



GLOCAL
UNIVERSITY
SHAPING GLOBAL MINDS

ISSN: 3107-474X (Online)

**JOURNAL OF
ENGINEERING,
SCIENCE AND
SUSTAINABILITY**

(Official Journal of Glocal University published by Sprin Publisher)

SP
Sprin Publisher

*An International
Research Publisher*

**J
E
S
S**

Volume 1, Issue 2, Jul-Dec 2025



Journal of Engineering, Science and Sustainability (JESS)

(ISSN: 3107-474X)

Official peer-reviewed journal of Glocal University

Volume 1, Issue 2, Jul-Dec 2025

Web-Link: <https://sprinpub.com/jess>

CHIEF-PATRON

Mr. S. Nizamuddin

Hon'ble Additional Pro-Chancellor

PATRON

Prof. (Dr.) Hridaya Shanker Singh

Hon'ble Vice Chancellor, Glocal University, India

Ms. Shivani Tiwari

Registrar

Advisory Members

Prof. (Dr.) T. Ahamad

Professor, King Saud University, Saudi Arabia, KSA

Prof. (Dr.) S. K. Sharma

Pro-Vice Chancellor, Glocal University, India

Dr. J. Finbe

Pro-Vice Chancellor, Glocal University, India

Prof. (Dr.) Sanjay Kumar

Director IQAC, Glocal University, India

ABOUT THE JOURNAL

The *Journal of Engineering, Science and Sustainability* is an official refereed publication of [Glocal University](#) and the publishing services are provided by Sprin Publisher. The journal is an international, open-access, bi-annual, peer-reviewed journal that publishes original research articles, reviews, communications, perspectives and case reports. Submissions are solicited in all topical areas ranging from engineering and technology to science and sustainability practices.

Journal Particulars	
Title	<i>Journal of Engineering, Science and Sustainability</i>
Abbreviation	J. Eng. Sci. Sustain.
Starting year of Publication	2025
Language	English
Mode of Publication	Online
Subject	Multidisciplinary
Frequency	Bi-annual

Aims and Objectives

The journal aims to serve as a premier platform for the dissemination of innovative research and advancements in the fields of engineering, science, and sustainability. It strives to bridge the gap between scientific inquiry and practical application, fostering technological progress and sustainable development. The journal is committed to publishing high-quality, peer-reviewed articles that advance knowledge and understanding in these domains.

Focus and Scope

The Journal invites original manuscripts in fields covering the aspects, but not limited to: Engineered and nanomaterials, Composite materials, Environmental Engineering, Biomaterials, Pollution, environmental issues, geo-environmental hazards, Carbon capture, Water splitting, Waste management, Renewable energy sources, Energy efficiency, catalysis, Energy storage, Applied science, Biomass Conversion, Desalination, Applied Chemistry, Bioenergy, Biocomposites, Circularity, Sustainable practices in Agriculture and pharmaceuticals, Biofertilizers, Biomaterials, Functional biopolymers, Natural Products, Biomass valorisation, AI, intelligent sensing, IoT, big data analysis for sustainable development.

The journal encourages submissions that support one or more of the 17 United Nation's sustainable developmental goals ([SDGs](#)).

EDITORIAL BOARD

Editor in Chief Dr. Mohd Yusuf

Associate Professor, Glocal University, India

Email: chiefeditor.jess@theglobaluniversity.in

Executive Editor	Dr. Wasim Khan Assistant Professor, Faculty of Engineering, Taibah University, Yanbu, KSA
Associate Editors	Prof. (Dr.) Salman A. Khan Chemistry Section, School of Sciences, Maulana Azad National Urdu University, India
	Dr. Sapna Jain Assistant Professor, Alabama State University, Montgomery, AL, US
	DR. TMM Marso Department of Chemical Sciences, South Eastern University of Sri Lanka, Sri Lanka
	Dr. K.K.M.S. Kandanapitiye Department of Nanoscience Technology, Faculty of Technology, University of Sri Lanka, Sri Lanka
	Dr. Umar Farooq Assistant Professor, Department of Chemistry, Galgotias University, Uttar Pradesh, India
	Dr. MNM. Farhath Assistant Professor, Department of Chemical Sciences, South Eastern University of Sri Lanka, Sri Lanka
	Prof. (Dr.) Shafat Ahmad Khan Professor, Department of Chemistry, Galgotias University, Uttar Pradesh, India
	Dr. Mohammad Shahid Assistant Professor, Mewar University, India
	Dr. Waseem Ahmed Assistant Professor and Dean (I/c), Glocal School of Arts and Social Science, Glocal University, India



Journal of Engineering, Science and Sustainability (JESS)

(ISSN: 3107-474X)

Official peer-reviewed journal of Glocal University

Volume 1, Issue 2, Jul-Dec 2025

EDITORIAL



Dr. Mohd Yusuf

It gives me immense pleasure and a deep sense of satisfaction to present the Second Issue of the Journal of Engineering, Science and Sustainability (JESS), covering the period July–December 2025. JESS is the official peer-reviewed journal of Glocal University, dedicated to promoting high-quality, original, and interdisciplinary research in the fields of science, engineering, technology, and sustainability.

The journal aims to provide a meaningful platform for researchers, academicians, scientists, and professionals to disseminate innovative research and exchange ideas addressing contemporary scientific and technological challenges. In particular, JESS seeks to encourage research that contributes to sustainable development and supports the broader objectives of the Sustainable Development Goals (SDGs).

This second issue brings together five research and review articles representing diverse and emerging areas of science and engineering. The contributions include phytochemical investigations of *Gymnema sylvestre* and *Vigna unguiculata*; a novel approach to Word Sense Disambiguation in Natural Language Processing; studies addressing industrial safety and hazardous materials management; a review of the therapeutic potential of boronic acid derivatives; and an exploration of nanoparticles in targeted drug delivery systems, particularly in the context of sustainable development and the SDGs.

The diversity of these contributions reflects the interdisciplinary character of JESS and highlights the increasing importance of integrating scientific innovation with societal needs and environmental sustainability. The articles published in this issue demonstrate how

contemporary research can contribute to addressing challenges in healthcare, computational science, industrial safety, natural products, and advanced materials.

The publication of this issue is also a significant milestone in the journey of JESS. I sincerely appreciate the valuable contributions of the authors, the constructive efforts of reviewers, and the dedicated support of the editorial and technical teams. Their collective efforts have been instrumental in maintaining the academic quality and timely publication of the journal.

I would also like to express my sincere gratitude to the Hon'ble Vice-Chancellor, Registrar, members of the editorial team, reviewers, authors, and the entire Glocal University community for their continued encouragement and support. As JESS continues to grow, we remain committed to strengthening its academic standards, expanding its interdisciplinary reach, and creating greater opportunities for researchers to share impactful and innovative work. We look forward to receiving high-quality contributions from researchers across India and around the world.

Our team invites readers to explore the articles published in this issue and hope that they will stimulate further research, discussion, collaboration, and innovation in science, engineering, and sustainability.

Dr. Mohd Yusuf
Editor-in-Chief
Journal of Engineering, Science and Sustainability (JESS)
Associate Professor & Dean, School of Science
Glocal University, India

CONTENTS

About the Journal	iii
Editorial Board	iv
Editorial	v
Contents	vii
Examine the Role of Web Technologies in Modernizing Library Management Systems (LMS) DOI: https://doi.org/10.55559/jess.v1i2.583	1-5
Next-Gen Collection Strategies: Exploring the Role of Artificial Intelligence in Library Science DOI: https://doi.org/10.55559/jess.v1i2.584	6-18
Book Review-Biomedical Textiles: Introduction and Applications DOI: https://doi.org/10.55559/jess.v1i2.586	19
Enhancing Machine Learning Model Security in Private Cloud Environments through Cryptographic Techniques DOI: https://doi.org/10.55559/jess.v1i2.587	20-23
Insights into E-waste as Global Concern: Sources, Composition and Impacts DOI: https://doi.org/10.55559/jess.v1i2.588	24-30
Foundations, Frameworks, and Evolving Paradigms of Environmental, Social and Governance (ESG) DOI: https://doi.org/10.55559/jess.v1i2.637	31-36

Perspective

Examine the Role of Web Technologies in Modernizing Library Management Systems (LMS)

Sumeeta¹, Sanjay Kumar Sharma^{2*}

^{1,2}Shri Venkateshwara University, Gajraula (U.P.) India



ARTICLE INFO

ABSTRACT

Keywords:

Web technologies, Library Management Systems (LMS), OPAC, cloud computing, mobile applications, Artificial Intelligence (AI), Internet of Things (IoT)

Article History:

Received: 01-10-2025

Accepted: 01-12-2025

Published: 06-12-2025

This review paper discusses the revolutionary effect of web technologies in modernizing library management systems (LMS) and their effects on increasing efficiency, accessibility, and user engagement. Traditional libraries, which were previously dependent on manual operations, are now transformed into digital, interactive, and networked global information centers with the incorporation of Online Public Access Catalogues (OPACs), electronic repositories, cloud computing, and mobile apps. They enable easy access to resources, automate cataloging and circulation, and enable cost-effective scalability. The assessment emphasizes the impact of cutting-edge technologies, including artificial intelligence (AI), blockchain, big data analytics, and Internet of Things (IoT), which allow intelligent search, secure transactions, data-driven decision-making, and real-time tracking of resources. Besides, Web 2.0 technologies like wikis, blogs, and social networking have transformed users' interaction via collaborative learning and interactive sharing. Despite ongoing challenges like high costs, copyright complexities, non-standardization, and inefficient staff training, advantages of modernization well outweigh these constraints. Through cloud-based and web-based technologies, libraries can continue their services, promote inclusivity, and change to respond to the changing demands for research, learning, and community development. Web technologies hence play an intrinsic part in redefining the role of libraries in the modern age.

1. Introduction

The integration of web technologies into active, interactive portals enhancing sharing of resources, accessibility, and efficiency has transformed traditional library management systems. The old libraries were manual or stand-alone software-based systems, limiting accessibility and operations. With web-based technologies such as digital repositories, on-line catalogues, cloud computing services, and mobile platforms, libraries are capable of providing easy accessibility to information anywhere and anytime. These technologies not only modernize library services but also make the user experience more enjoyable, facilitate collaboration, and satisfy the growing demand for digital information in education and research.

1.1 Emergence of Web Technologies in Libraries

Application of internet technology by libraries has transformed the process of people accessing, classifying, and disseminating information. Libraries previously were geographical facilities with cascading cataloging, circulation, and record-keeping processes that were time-consuming, inaccurate, and geographically limited (Das & Lahkar, 2024). The advent of the internet and web technologies in the closing years of the 20th century created a paradigm that allowed libraries to make the transition to electronic, networked settings that dispense information resources in handy, point-of-access locations. Web-

based library management systems (LMS) have been created to support actions like digital borrowing, network sharing of resources, and online public access catalogues (OPAC) in response to the growing need for effectiveness, accessibility, and instantaneous information retrieval (Moradi, Bagher, & Mirhosseini, 2017).

As web technologies such as HTML, CSS, JavaScript, and server-side scripting languages offered the basics for interactive and user-friendly interfaces, databases and server architectures-maintained data consistency, security, and scalability (Khan, Rafi, Zhang, & Khan, 2023). Cloud and open-source systems such as Koha, NewGenLib, and NextGenLib have utilized the above technologies to offer flexible and affordable solutions that can be accessed by small public libraries and large academic establishments (NewGenLib, n.d.; NextGenLib, n.d.). Through automated cataloguing and acquisition, interlibrary loan requests, off-site access, and tailored services such as recommendation engines and notice generation, these systems offer better user experience and efficiency in operations. Library services were also transformed by Web 2.0 technologies that enhanced collaboration, communication, and user involvement. Libraries are now changed from passive repositories to active knowledge communities through the application of wikis, blogs, RSS feeds, and social media integration, enabling users to review resources, create content, and participate in discussions (Moradi et al., 2017).

* Corresponding Author:

✉ saberwals@gmail.com (S. K. Sharma)

doi: <https://doi.org/10.55559/jess.v1i2.583>

© 2024 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

 <https://creativecommons.org/licenses/by/4.0>

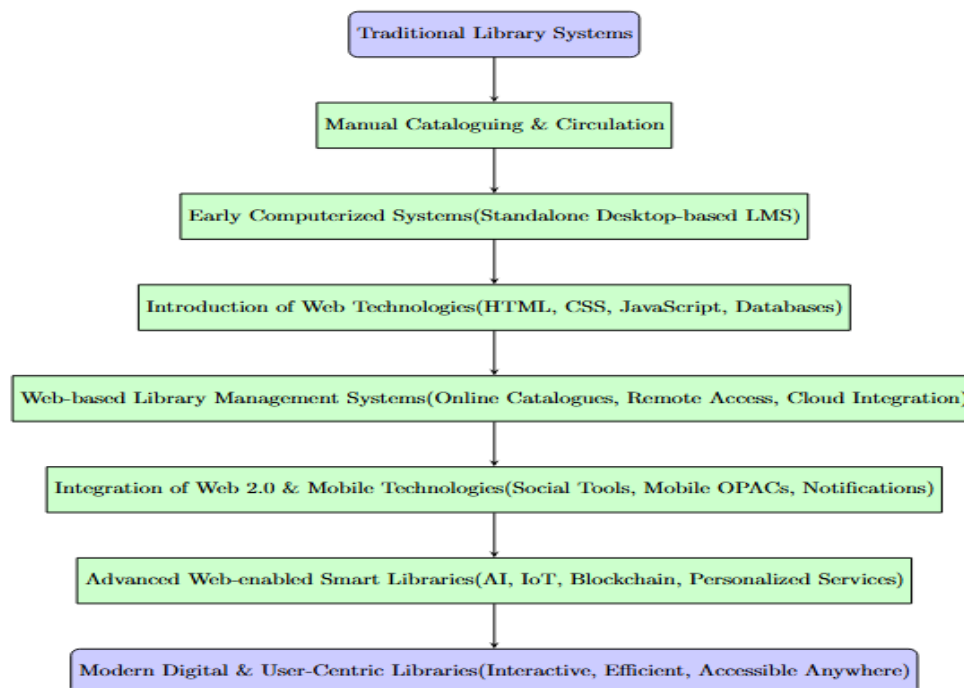


Figure 1: Evolution of Library Systems through the Emergence of Web Technologies.

Although responsive designs and mobile-friendly web applications extended the library's reach by making customers able to use services through smartphones and tablets, cloud computing likewise raised service scalability and lowered infrastructure costs (Das & Lahkar, 2024). Moreover, to deliver more advanced and secure services, web-based library systems are embracing advanced technologies such as blockchain, Internet of Things (IoT), and artificial intelligence (AI). IoT facilitates real-time tracking of library resources, blockchain provides data integrity and secure digital transactions, and AI facilitates automatic classification, personalized suggestions, and natural language searching (Sambari, Sreeramoj, & Vinay Kumar, 2024). Together, these technologies illustrate how libraries have transitioned into user-centric, technology-enabled institutions with a focus on effectiveness, innovation, and access. Generally, web technologies have provided libraries with the opportunity to develop along with the fast-evolving digital environment and even modernize conventional library procedures. As part of a significant shift towards the further revolution of information services, libraries can facilitate more research, learning, and community involvement by introducing interactive, intelligent, and networked systems (Khan et al., 2023).

1.2 Impacts of ICT On Academic Libraries

Scholarly libraries have seen a revolutionary change in their roles, services, and organizational structures since the advent of information and communication technology (ICT). One of the most dramatic impacts has been shifting from conventional collection-based to user-oriented, service-based models. With the help of integrated library management systems (ILMS) through ICT, library operations like acquisitions, cataloging, circulation, and serials management have been automated. This has enhanced efficiency, precision, and resource utilization (Das & Lahkar, 2024). Academic libraries today overcome spatial and temporal impediments to information through institutional repositories, e-resources, and Online Public Access Catalogues (OPACs), which offer distant, round-the-clock access to scholarly information (Moradi, Bagher, & Mirhosseini, 2017).

In educational institutions, ICT has further widened the range of support for teaching, learning, and research. While ICT-based services such as digital reference, information literacy instruction,

and current awareness services enhance scholarly productivity, digital libraries, e-journals, e-books, and open access resources enhance access to scholarship. Increased engagement with library resources is fostered by the interactive, collaborative, and tailored learning experiences that cloud-based platforms, mobile apps, and Web 2.0 technologies bring to teachers and learners (Khan, Rafi, Zhang, & Khan, 2023). In addition, ICT has allowed academic libraries to employ AI-based tools and big data analysis, which facilitates recommendation systems, predictive services, and enhanced decision-making in collection development and resource allocation (Sambari, Sreeramoj, & Vinay Kumar, 2024).

ICT's role in preserving and sharing institutional knowledge is another significant impact. Obscure manuscripts, theses, and dissertations are now accessible globally through digitization efforts and institutional repositories and are bringing scholarship into greater awareness. RFID and IoT technologies have also improved security at the library and inventory management, and blockchain technology is being researched for digital rights management as well as content authenticity.

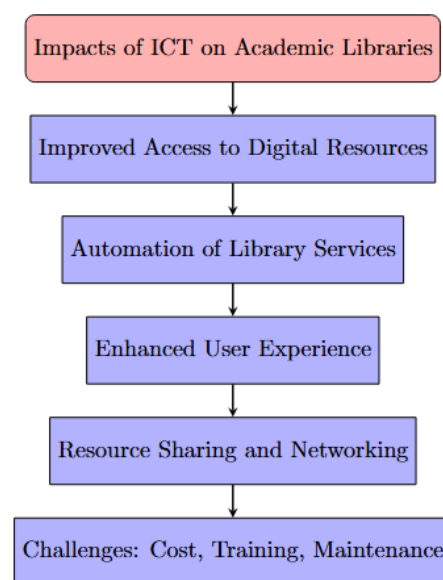


Figure 2: Impact of ICT to the Academic Libraries.

2. Use Of Modern Information Technology in Library Services

Through their expansion of coverage, enhanced access, and improving operational effectiveness, application of modern information technology (IT) has transformed library operations. Previously, libraries used to trust mostly time-consuming, prone-to-error manual processes in cataloguing, circulation, and reference services. These services have been significantly modernized through the use of advanced technologies such as automation software, cloud computing, artificial intelligence (AI), big data analytics, and mobile applications (Khan, Rafi, Zhang, & Khan, 2023). Acquisitions, cataloguing, and serials control are currently automated through Integrated Library Management Systems (ILMS), making them more accurate and time-saving (Das & Lahkar, 2024).

Just like this, cloud-based systems ensure smooth connectivity at the expense of reducing infrastructure costs through the provision of resource sharing, scalability, and remote access

(NextGenLib, n.d.). Moreover, user services are increasingly interactive and personalized. While mobile-friendly applications ensure 24/7 usage, Online Public Access Catalogues (OPACs) facilitate remote search, reservation, and renewal (Moradi, Bagher, & Mirhosseini, 2017). While big data analytics helps with collection management and user preference understanding, artificial intelligence (AI) makes intelligent search, recommendation systems, and natural language processing possible (Sambari, Sreeramoj, & Vinay Kumar, 2024). Additionally, community involvement and reference services are strengthened by modern IT. While Web 2.0 tools and social media platforms encourage collaboration, feedback, and user participation, virtual reference desks, chatbots, and email support provide assistance outside of physical libraries. Rare manuscripts, theses, and academic resources are accessible worldwide thanks to digitization and institutional repositories.

Table 1: Applications of Modern Information Technology in Library Services

Technology / Tool	Application in Libraries	Reference
Integrated Library Management Systems (ILMS)	Automates cataloguing, acquisitions, serials control, and circulation, reducing errors and saving time.	Das & Lahkar, 2024
Cloud Computing	Enables remote access, resource sharing, scalability, and reduced infrastructure costs.	NextGenLib, n.d.
Web-based OPACs & Mobile Apps	Provides remote book search, reservation, renewal, and mobile accessibility.	Moradi, Bagher, & Mirhosseini, 2017
Artificial Intelligence (AI)	Enhances information retrieval through recommendation systems, intelligent search, and natural language queries.	Khan, Rafi, Zhang, & Khan, 2023
Big Data Analytics	Helps analyze user behavior, track resource usage, and support data-driven collection development.	Sambari, Sreeramoj, & Vinay Kumar, 2024
Digital Reference Services	Provides real-time assistance via chatbots, email, and virtual reference desks.	Khan et al., 2023
Web 2.0 & social media Tools	Facilitates user engagement, feedback, online tutorials, and collaborative knowledge sharing.	Moradi et al., 2017
Digitization & Repositories	Offers open access to theses, dissertations, research papers, and rare manuscripts globally.	Das & Lahkar, 2024
RFID & IoT	Streamlines circulation, automates inventory management, and prevents theft/misplacement.	Sambari et al., 2024
Blockchain Technology	Provides secure digital rights management, authenticity checks, and transparent transactions.	Sambari et al., 2024

3. Factors Affecting Information Technology in Modern Librarianship

There are several obvious reasons:

- **Cost:** While the effects on publishers and libraries have garnered a lot of attention as of late, we can't ignore the potential consequences for users who may soon be required to pay to utilize online databases, search optical disc files, and print out abstracts.
- **Lack of standards:** Manufacturers of hardware adhered to separate standards up until quite recently. While standards like High Sierra seem to be easing software publishers' burdens when dealing with CD-ROM technology, others, like telefacsimile, still need to be created.
- **Lack of perceived market.** When it comes to new technology-based items, publishers don't see a library market. Consider the low number of libraries and the fact that almost no one has their own optical disk or CDROM drive for their own computers. A number of companies have begun to mimic the business model of bibliophile, which included selling the goods with the disks. The market is still quite small.
- **Content of disc.** There are more than 500 megabytes on a 5-inch CD-ROM. Publishers are struggling to find sensible ways to organize all that data onto discs because there is just so much of it. Color and graphics are only now becoming widely accessible. People aren't prepared to completely abandon printed pages in favor of digital information just yet. The publish-or-perish cycle does not yet recognize publications published just online as legitimate contributions because academics do not yet trust electronic articles and because they may not undergo the same rigorous review process.
- **Copyright:** The growing information technologies were not covered by the 1976 copyright legislation, and the publishing and library sectors are trying to find a middle ground, but so far, they have only achieved partial success. As full text papers become more accessible in electronic form, the copyright problem is only going to escalate.
- **Lack of staff training:** Since the majority of library employees aren't very tech-savvy, the app and some library sections aren't very user-friendly either.

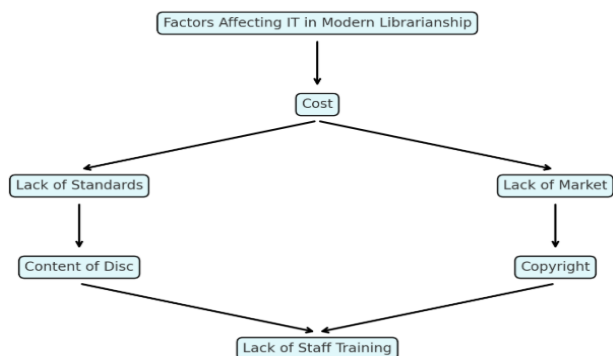


Figure 3: Key Factors Influencing IT in Modern Librarianship.

4. Applications of ICT in Academic Libraries

Since the introduction of information and communication technology (ICT), academic libraries have evolved to become more efficient, accessible, and user-friendly. One of the primary applications is the Online Public Access Catalogue (OPAC), which has replaced conventional card catalogues and makes it simple for users to search, identify, and reserve items. ICT has expanded access to digital and electronic resources, including databases, e-books, and e-journals, enabling researchers and students to access material anywhere at any time. Libraries are increasingly using Integrated Library Management Systems (ILMS) to automate acquisitions, cataloguing, serials control, and circulation. This not only saves time but also enhances precision and minimizes human error in mundane tasks.

Another important use is the creation of institutional repositories and digital archives where research results, theses, and dissertations are stored and made available to the general public. Thanks to ICT's support for virtual reference services like chat, email, and AI-powered tools, users may obtain assistance without physically visiting the library. Furthermore, ICT makes networking and resource sharing easier via cloud-based platforms and library consortiums, providing access to a wider range of materials at a lower cost. Sophisticated technologies such as RFID and the Internet of Things (IoT) are progressively being applied in inventory management, automated check-in/check-out mechanisms, and theft deterrents.

5. Conclusion

Web technologies alter and are essential to library management system modernization. Libraries have become dynamic centers of information and cooperation by switching from labor-intensive approaches to digital, automated, and user-centered platforms. OPACs, digital repositories, cloud computing, and mobile apps make materials accessible 24/7. Artificial intelligence, big data analytics, blockchain, and the Internet of Things (IoT) have improved library efficiency, accuracy, security, and user experience. Libraries are becoming dynamic venues that promote participation, feedback, and shared learning thanks to Web 2.0 and social media. Technological adoption is worth the financial, copyright, standardization, and staff training problems. Libraries that adopt these technologies satisfy digital-age users' needs and reinforce their role in research, teaching, and community development. Libraries must invest in new technology, staff training, and user-friendly systems to survive. Web technologies have changed library administration by promoting inclusion, creativity, and worldwide connectedness, ensuring that libraries remain crucial to academic and social growth in the 21st century.

6. Acknowledgement

None.

7. Funding

None.

8. Conflict of Interest

None.

9. References

- Bhati, P., Komal, N., Prince, N., & Saxena, S. (2024). MODERN LIBRARY MANAGEMENT SYSTEM: a WEB-BASED FRAMEWORK FOR RESOURCE AUTOMATION AND USER OVERSIGHT. *International Journal of Research - GRANTHAALAYAH*, 12(6). <https://doi.org/10.29121/granthaalayah.v12.i6.2024.6099>
- Jharotia, Anil. (2021). Role of Web Technology and Internet in Library Management System based on Digital Platform.
- Araya, N. T. W. (2020). Designing web-based library management system. *International Journal of Engineering Research And*, V9(10). <https://doi.org/10.17577/ijertv9is100131>
- American library association (2006) Guidelines for University Library Services to Undergraduate students, Chicago.
- Boston library consortium (1986) Managing Technological Change: Boston.
- Busch,B.J.,(1986) 'Integration of Public and Technical Servives functions; observations on organizational change' in Six Member Library of the Association of Research Libraries: Washington.
- Chisenga,M.,(1999) ICT in Libraries: An Overview and General Introduction of ICT in libraries in Africa. Paper presented at INASPICT workshop in Johannesburg, South Africa on 21st to 23rd July 2004.
- Devchoudhary G.B., (2009) ICT and Electronic Library: Management and Delivery within the Traditional Library.
- Govan, J.F., (1987) 'Fludity and Intangibility: The stunning impact of an Expanded Information Base *Journal of Library Administration*.
- Ifidon S.E., (2006) Modern Theory and Practice of Library Collection Development, Benin City: Justice Jeco Publishers.
- Martin K.S., (1989) Library Management and Emerging Technology: The Immovable Force and Irresistible Object.
- Mohammed,H.,(2004) The Relevance Of Information And Communication Technology To Information Professionals Of The Digital Age: Challenges For Library And Information Centres.
- Mosuro (2000), Potential Impact of New Information Technology on Libraries and The Library User, Library Automation for The Information Age: Concepts, Technologies and Strategies.
- Nebeolise,L.N., (2013) The Impact Of Information And Communication Technology (ICT) Compliant Libraries On Library Services Delivery In Academic Library: The Case Of National Open University Of Nigeria (NOUN) Library In The *International Journal Of Engineering And Science (IJES)*Vol-II, Issue 8.
- Nwalo K.I.N(2000)' Collaboration in The Provision and Utilization of IT Facilities for Library And Information Science Education In Nigeria'. In Papers Presented at That 10th Biennial Conference of Nalise.
- Hugh Kenneri (1986) Analysis of The Current Challenges in Accessing Legal Information.
- Oyedun (2007) Information Technology Quality Assurance and Academic Library Management Library Philosophy and Practice *E Journal*.
- Saleem A. S., Tabusum, S., & M, S. B. (2018). Application and Uses of Information Communication Technology (ICT) in Academic Libraries: An Overview. *ResearchGate*. <https://doi.org/10.5923/j.library.20130203.01>
- Das, P. R., & Lahkar, N. (2024). Modernization of library services of central universities in North East India in the domain of

- mobile technology: A study. *Indian Library Association Journal*.
- Khan, A. U., Rafi, M., Zhang, Z., & Khan, A. (2023). Determining the impact of technological modernization and management capabilities on user satisfaction and trust in library services. *Global Knowledge, Memory and Communication*, 72(6–7), 593–611.
- Barman, D., & Das, D. (2025). A systematic review of Web 2.0 technologies in library websites (2010–2023). *Granthaalayah*, 13(8), 1–12.
- Khan, S. A. (2024). Key features of digital library management system (DLMS). *Journal of Librarianship and Information Science*, 56(1), 34–48.
- Giri, R. (2015). NewGenLib 3: An integrated open source library management system that makes your library visible in web. *ResearchGate*.
- NextGenLib. (2024). Digitization of libraries: An integrated library management system.
- Khan, R., Rafi, M., Zhang, L., & Khan, A. (2023). *Modern information technology and its impact on library services*. Springer.
- Moradi, H., Bagher, H., & Mirhosseini, M. (2017). Web-based services in academic libraries: Enhancing accessibility and user experience. *Journal of Library & Information Services*, 12(3), 45–59.
- NextGenLib. (n.d.). *Cloud-based library management solutions*. Retrieved from institutional database.
- Sambari, S., Sreeramoj, R., & Vinay Kumar, P. (2024). *Big data analytics in library management: Understanding user preferences and trends*. Elsevier.
- Khan, R., Rafi, M., Zhang, X., & Khan, S. (2023). *Advancements in library automation and digital services*. Springer.
- Moradi, F., Bagher, M., & Mirhosseini, M. (2017). *Enhancing library services through web-based and mobile technologies*. *Library Science Review*, 29(3), 45–60.
- NextGenLib. (n.d.). *Cloud-based library solutions and integrated management systems*. NextGen Library Publications.
- Sambari, R., Sreeramoj, R., & Vinay Kumar, P. (2024). *Big data analytics in libraries: Understanding user behavior and improving services*. *Journal of Library Innovation*, 15(1), 12–28.



Research article

Next-Gen Collection Strategies: Exploring the Role of Artificial Intelligence in Library Science

Urvashi Tyagi^{1*}, Sanjay Kumar Sharma²

^{1,2}Shri Venkateshwara University, Gajraula (U.P.) India

ARTICLE INFO

ABSTRACT

Keywords:

Artificial Intelligence, Library Science, Collection Development, Recommendation Systems, User Engagement

Article History:

Received: 01-08-2025

Revised: 20-11-2025

Accepted: 01-12-2025

Published: 07-12-2025

This research explores how Artificial Intelligence (AI) might improve collection techniques in library science, with a focus on effectiveness, user involvement, and creative collection building. A structured online questionnaire with verified Likert-scale questions It was utilized to gather information from 384 participants using a quantitative research technique. Key concepts such AI-powered technology, user engagement, AI-driven recommendation systems, efficiency in library collection creation, and library staff efficiency are the focus of the inquiry. The representativeness of the sample is guarantee using a stratified random sampling procedure, and the analysis is bolstered by secondary data gathered from institutional records, government publications, and earlier studies. SPSS is used for statistical analysis in order to evaluate structural connections, validity, and dependability. The structures' good validity and reliability were confirmed by the results, indicating that they are appropriate for further study. Based on descriptive findings, consumers highly regard AI-based recommendation engines and advanced collection creation methods, whereas employees' efficiency is mostly perceived positively but remains to be improved. Testing hypotheses confirmed that AI is a major impact on user engagement and the growth of library collections. Notably, AI improves engagement both directly and indirectly via better staff performance, as seen by the mediation impact of staff efficiency. The correctness and resilience of the suggested framework are further confirmed by structural model fit indexes. All things considered, the results show that the implementation of AI is a key factor in improving library user engagement, strategic collection development, and operational efficiency. By offering empirical proof of AI's ability to transform collection tactics and change the role of library professionals, this research adds to the expanding conversation on next-generation library practices. The conclusions drawn have applications for academics, library administrators, and legislators who want to leverage AI-powered technology to provide sustainable and user-focused library services.

1. Introduction

Libraries are employing artificial intelligence (AI) to perform tasks such as automated indexing of collections, library service tasks, prediction of reader needs, and optimization of storage placement of books. AI is increasing its presence in our everyday lives. Since it provides computational techniques for automatically learning new information, this technology is critical to the development of intelligent libraries. A machine learning method named Transformer is utilized to train OpenAI's ChatGPT, which is a deep language model, to understand and generate text in natural language. However, says The Curriculum for Media and Information Literacy by UNESCO Educators and Learners, AI also threatens information literacy [1]. To chart important themes for future library development and operations, this research investigates the effects of using AI in libraries a form of information technology advancement. It emphasizes pedagogical strategies for educating library staff in AI skills. The fundamental mission of libraries has always been around knowledge retention and fair access to information. In the opinion of Nancy Kranich, American Library Society's president, libraries are "uniquely positioned" to make the playing field even by offering "content and services for all people" [2]. Public libraries in specific have served communities as egalitarian institutions that encourage self-education and literacy as stepping stones to individual progress and active citizenship [3]. Artificial intelligence (AI) is robots'

capacity to exhibit human-like characteristics such as learning, thinking, understanding language, recognizing objects, and decision-making [4]. It is a broad field that encompasses a variety of technologies, including as natural language processing and machine vision. Machine learning (ML) is a kind of artificial intelligence that allows computers to gain knowledge from data without the need for explicit programming. Machine learning algorithms discover patterns in data, recommendations, or decisions so that humans do not need to specify all the rules explicitly in order to make predictions [5]. Looking at the shifting landscape of AI research in library science from a bibliometric point of view is what gives this study its importance. Libraries face a number of challenges in meeting the changing needs and expectations of their patrons in the era characterized by exponential growth in digital material and rapid technical advancements. One possible solution to these issues is the implementation of AI, which enables libraries with characteristics to improve user experiences, maximize the use of resources, and accelerate processes [6]. Using a rigorous bibliometric analysis, the aim aims to provide light on the trends and patterns influencing AI's influence on books. This study tries to offer meaningful insights on present and future orientations of AI studies in library science by analyzing quantitative publication output, research topics, cooperation networks, and citation patterns.

* Corresponding Author:

✉ tyagi.urvashi944@gmail.com (U. Tyagi)

doi: <https://doi.org/10.55559/jess.v1i2.584>

© 2024 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

 <https://creativecommons.org/licenses/by/4.0>

Libraries are experiencing a revolutionary transformation through artificial intelligence. This implies that intelligent technologies are being utilized to enhance things. Information organization and discovery are accelerated by AI. Imagine it as the library's friendly virtual assistant. may point you in the direction of what you need or suggest books. Consider how much faster it would be to organize and classify books, for example. AI is capable of doing that, saving time. seek more assistance from the library staff [7]. Several challenges, of course. We must ensure that everyone who visits a library is comfortable with artificial intelligence and that privacy is secured. investigation examines actual cases and narratives to demonstrate how AI is already changing libraries. To put it simply, AI is transforming the way libraries operate. Although it's fascinating, we must utilise technology carefully to ensure that it supports libraries' mission and values. AI makes intelligent technology possible, such as virtual assistants and sophisticated algorithms. AI for libraries may be likened to a librarian who never sleeps.

The use of artificial intelligence (AI) is spreading across many industries and occupations, making it a powerful force in research and scholarly discourse. Increased productivity, better customer service, educated decision-making, individualised experiences, less risks and mistakes, and higher efficiency are some of its advantages. Despite being slower to incorporate AI, academic libraries are catching up over time. Though interest in incorporating AI into libraries has grown over the last five years, the concept has been around since 1985. The main effects of AI on libraries include sophisticated cloud service identification for online material, next-generation browsers that use semantic analysis, and voice Machine translation and detection for instantaneous multilingual support [8]. AI in academic libraries has a lot of promise to increase information access in novel ways, optimise processes, and improve user experiences. Numerous studies examine artificial intelligence (AI) with special focus on AI-based solutions for educational libraries, advantages, difficulties, adoption methods, and Academic libraries' preparedness to incorporate AI into their resources and offerings. Research also looks at how librarians see AI technology and how they feel about them. Among the most fundamental roles of university libraries is to ensure that all users including faculty, students, and staff have ready access to relevant, up-to-date material. By collecting, conserving, and making library materials accessible University libraries have a responsibility to encourage intellectual pursuits and inquiry among its patrons, including faculty, pupils, and others. Consequently, the university sector and higher education depend heavily on university libraries [9]. By supporting the institutions' research, teaching, and learning initiatives, they help them achieve their goals and missions. University libraries use robotic technology to streamline operations, simplify and improve services, and foster efficiency in order to successfully carry out their mission. Robotics is described differently by various academics. According to, robots are mechanical devices that utilise artificial intelligence (AI) methods to automate jobs that are currently under direct human supervision or that follow a predetermined program and set of basic principles. Robots, according to, are robots that can do a variety of automated tasks things computers have programmed. According to these two meanings, One area of artificial intelligence called robotics is concerned with machine learning, perpetual tasks, and motor tasks.

"Library" is a reference to the Latin word "liber," meaning "book." "Bibliotheca" is a synonym for in Greek and Romance languages. A more suitable definition may be provided by a

collection of books and/or other written or non-printed resources that are kept up to date and arranged for potential use (e.g., reading, consultation, study, research). Institutional libraries employ librarians and other staff members who have received training in meeting user requirements, and they are set up to make access easier for a particular user demographic [10]. The Persian word hane, which means libraries-house, which is a location where books are gathered, and the Arabic term kitab, which is the plural of kütüb, sources of the Turkish word "kütüphane," which means library. The Arabic term "kitab" comes from the words "writing" and "name." Libraries serve a variety of audiences and fulfil a variety of purposes depending on their kind. Public libraries support researchers and students in higher learning, whereas university and school libraries often provide books and resources to everyone for free. National libraries safeguard a nation's literary and historical legacy, whereas special libraries serve specialised disciplines like law or medicine [11]. Libraries are establishments that preserve the intellectual, cultural, and educational legacies of many civilisations and are crucial to the growth of society and the scientific community. We may infer the origins of modern science and culture from the scientific and cultural interactions that numerous ancient civilisations had with one another and/or with succeeding civilisations. The most significant repositories of the intellectual accumulation that results from this interaction are libraries and archives. Library automation systems have been in use from the late 1980s and early 1990s. has progressed from its invention to widespread deployment. The library's materials and services have undergone significant changes due to technological advancements during the last two decades, particularly in the last decade. Particularly in scientific and special collections, books are quickly being supplanted by digital materials as the main library resource. Other digital resources, including digital collections, institutional repositories, and e-books, have also gained popularity. Library patrons expect quick and simple access to library materials and services, similar to how they obtain information in the digital era [12]. The library automation system, commonly known as the integrated library system (ILS), has remained mostly unchanged over the previous two decades. The library's process and environment are constantly evolving, making it challenging to manage. Library personnel express frustration with the ILS's inability to handle their regular tasks. The complexity of library applications and systems might lead to confusion among users. Library automation systems are on the verge of a significant transformation. The library literature refers to them as second-generation or next-generation automation systems. The second-generation library automation system has two pillars: (1) comprehensive and unified resource management regardless of format or location, and (2) a shift away from traditional ILS models towards service-oriented architecture (SOA). We are at the start of a new age for library automation systems. Vendors of library systems are developing and implementing second-generation automation systems in response to changing needs. We anticipate that the idea and execution of the new library automation system will swiftly spread across all sorts of libraries. This will improve library operations for both staff and patrons.

Libraries will remain dynamic in the years to come because the knowledge and services provided by the LIS community and profession will change along with the demands and expectations of academics. Libraries and LIS workers should take advantage of the tremendous technology possibilities and fast change that are occurring now. There is growing demand on librarians to be flexible and to identify what our library's clients may desire before they even realize it exists or that they need it. We must continue to monitor proactive and individual alerting methods such as Google Alerts, Change-Detect, Spy-on-it, and others [13]. In

contrast to Web 2.0, a term often used to characterize the alleged continuous The World Wide Web's development from a collection of websites to a fully functional computer system service, the next era of librarian has been named "Librarian 2.0." For a number of applications, Web 2.0 is eventually expected to replace desktop software. According to the Texas Library Association and Texas Library and Archives Commission, libraries are tools for creativity and are shaped by the ideas that society must maintain an open and public structure (systems) in a true democracy in order to inform and encourage a free-thinking populace for advancement of services.

Skills Library Staff Need in the Future

Since a librarian demonstrates the ability to provide library programs, services, and tools that are essential to the current academic environment and knowledge era, their work is highly diverse and vital. constantly evolving data requirements of students as well as in providing support to academic staff who are involved in study, information creation, and lecture-room teaching. In order to accomplish fundamental objectives that support the university's mission and vision, librarians need to possess both the intellectual capacity and the skills necessary to successfully accomplish these objectives. IT, instruction, interaction, organizing, and planning

- Proficiency in writing and spoken communication, together with the ability to negotiate or bargain, is essential for teaching and fostering relationships between libraries.
- Communication skills are intimately linked to training skills. To teach users how to use new technologies, distribute specific information, and provide knowledge, bibliographic guidance, and user education, a librarian must possess training skills.

- The ability to use technology to help libraries in the ICT era carry out their tasks efficiently.
- Planning and organizing abilities that support short- and long-term planning for the library; the capacity to prioritize tasks and organize one's workload due to the abundance of requests.
- Project management abilities as well as entrepreneurial and proactive talents that support creative results and outputs. The majority of libraries must start and complete initiatives with deadlines that must be closely followed.
- Relational and teamwork abilities that support fruitful working relationships and results.
- Learning and ability to manage themselves, together with a willingness to further their professional and career goals, are essential for librarians. These abilities support the continuous development and growth of the librarian's expertise, which improves the activities, results, and outputs of the library or institution.

Additionally, the modern librarian requires a wide range of additional abilities and character traits. For instance, dedication to serving the needs of library patrons, capacity to manage obligations at work and at home, flexibility and readiness to work under pressure, and adherence to moral principles, integrity, and quality control.

1.1 THE ROLE OF AI IN LIBRARIES

AI is having a big effect on modern libraries. It is changing many facets of the library's operations, offerings, and patron experiences. These are a few of its most significant facts:

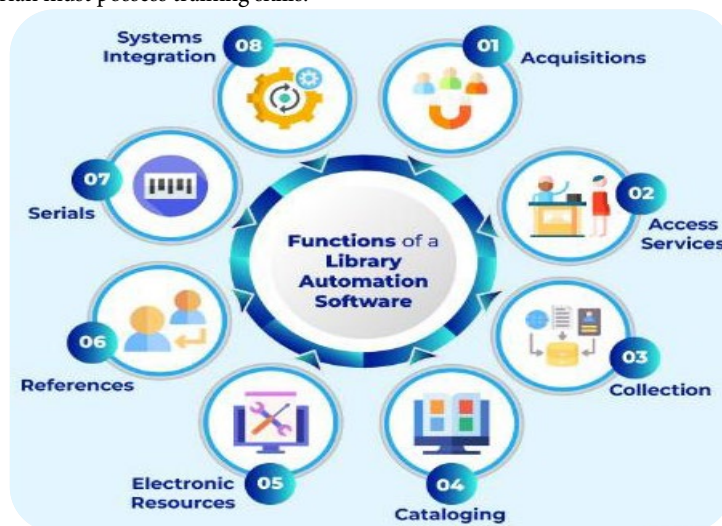


Figure 1 Function of an automation software

- **Curation and recommendation systems:** AI algorithms look at a user's preferences, borrowing history, and reading patterns to provide tailored recommendations. These resources assist users in finding the appropriate books, articles, and further materials faster.
- **Information retrieval:** Algorithms for artificial intelligence search engines enable easy information retrieval from databases and library catalogs. Techniques for Natural Language Processing (NLP) improve search accuracy by comprehending and answering queries of users.
- **Digital archives and preservation:** AI is helping libraries to preserve old and fragile items. It is able to scan them, converting them into digital formats that can be searched by

anyone. And AI can categorize and organize these digital files., which is quite a relief.

- **Chatbots and virtual assistants:** Libraries use AI chatbots, helpers to give folks quick help. They answer questions and guide them to the stuff they're looking for. These helpers are always on, which makes getting in touch way simpler.
- **Text analysis and data mining:** Libraries can use AI technologies include sentiment analysis and text mining., to pull useful info from tons of text. Librarians can then use what they find to see how people are using the library, help with research, and put together better collections.
- **Content creation and generation:** AI helps make writing easier by creating things like metadata, abstracts, or

summaries. This lets librarians focus on important stuff rather than getting stuck on boring tasks.

- **Accessibility services:** AI can really help people with disabilities get what they need from libraries. Like, there's software that uses AI to help people who can't see use computers and hear text read aloud.
- **Predictive analytics for collection management:** Libraries use data to guess what resources they'll need in the future. This helps them improve their collections and inventory control. AI looks at usage and outside stuff to make these decisions.
- **Security and fraud detection:** Libraries are using artificial intelligence (AI) to beef up security, like spotting fraud, managing who goes where, and guarding their online stuff.
- **Language translation services:** Libraries that have books and stuff in different languages can use computer translation to help people read them in other languages. This way, more people can get to enjoy what the library has.

Libraries have been used as information distributors and repositories for thousands of years. This vast volume of information has to be well organised in order to be accessible. Thus, organising knowledge is one of the library's primary responsibilities. As technology develops, people must live up to ever-increasing standards. The capacity of Artificial intelligence (AI) is the ability of a digital computer, software-controlled device, or software to reproduce intellectual characteristics, that are comparable to those of sentient beings (humans) in their functioning. The utilisation of information resources, search functionalities, and the speed at which requests are handled will all be impacted by the library's incorporation of AI [14]. Through social networking and mobile platforms, AI technology can be used to create new immediate digital reference services by combining material from third parties with the resources currently found in libraries. Moreover, some additional fascinating uses Robotics, AI in libraries includes things like natural language processing and sorting algorithms. The application of AI in libraries is growing. These involve, for example, deep learning using virtual reality, library expert systems, and robots that read books and stores. Despite the notion that incorporating AI into libraries will make librarians more distant from their patrons, in reality, it will probably enable libraries to do more. Additionally, AI will modernize libraries, significantly enhance operations and facilities, and raise their importance in a quickly changing digital world.

Large data, artificial intelligence (AI), machine learning (ML), natural language processing (NLP), and other data science-related ideas are among the new technical advancements that are sweeping the academic community. Public service providers may seem less aggressive than commercial players, such as publishers and numerous start-ups, who are actively investigating AI to improve their services and manufacturing methods. The heart this change are research libraries that support academic institutions and other intellectual groups. In order to support their operations and services, they look through library technology reports to select the best products, participate in national or international projects to benefit from cooperative technology development, and follow the developments of academic publishers and other close partners with conflicting emotions. Discussions about these new developments' effects on the research environment have surfaced [15].

The function of libraries is firmly defined ever since the global sustainable development initiative known as Agenda 2030 was put into action. The process of including libraries in this action program has been heavily influenced by the International Federation of Library Associations (IFLA). National policy also reflects this acknowledgment; example, the agenda 2030 roadmap in France acknowledges libraries as an essential component in the process of building a sustainable future by enlightening and

teaching people. Our cultures are seeing the emergence of a technology that also affects growth overall, while equitable growth sits at the nexus of social, economic, and environmental problems [16]. A remarkable amount of media attention has been paid to artificial intelligence (AI) technologies with the launch of in November 2022, the intelligent conversational platform ChatGPT was created. Artificial intelligence, creative intelligence, of which it is but one kind, is already an essential component of our digital life on a daily basis. When we browse social networks, when we use GPS to navigate, or when we obtain product suggestions on streaming or e-commerce platforms, we are able to find it.

Transforming Library Services with AI:

Libraries have always served as information and knowledge centres, but as artificial intelligence (AI) advances, they are seeing major changes in the way they interact with their users and provide services. 19. AI is revolutionizing library services in the following ways:

1. **Enhanced Search and Discovery:** How people search for library material is being entirely revolutionized with AI-driven indexing and recommendation systems. Through observation of user interest and behavior, AI systems can provide personalized recommendations, facilitating users' search for relevant content across large libraries.
2. **Automated Metadata Generation:** Utilizing artificial intelligence (AI) tools like natural language processing (NLP) and machine learning allows for the automation of library materials' metadata creation. This enhances resource visibility by making cataloging easier, saving libraries time, and ensuring continuity and accuracy in metadata.
3. **Virtual Assistants and Chatbots:** Chatbots and AI-powered robots are being utilized by libraries to offer users instant help. By making recommendations, helping patrons navigate the buildings, and answering common questions, these virtual assistants can potentially make patrons happier and more engaged.
4. **Data Analytics for Collection Management:** Libraries can take data-driven decisions regarding expenditures and collection building by using data analytics technologies based on artificial intelligence. Libraries may improve their holdings to satisfy the needs and goals of its patrons by analyzing usage trends, circulation statistics, and patron ratings.
5. **Digital Preservation and Access:** The scanning and library asset maintenance, especially of rare and fragile artifacts, are simplified through AI technology. More people can access physical documents by applying them to digital forms using picture recognition and optical character recognition (OCR) technology.
6. **Accessibility Enhancements:** Accessibility features powered by artificial intelligence, such as language translation and text-to-speech functions, allow users with disabilities or linguistic barriers to access more information with greater ease. Through these enhancements, libraries are able to provide for all members of the community in an equal and unbiased manner.
7. **Content Analysis and Insights:** Libraries can draw significant information from textual content, such as digital books and learned journals, through AI-driven analysis tools. Libraries can identify trends, themes, and trends that inform collection building and research projects through text mining and sentiment analysis.
8. **Predictive Analytics for Resource Allocation:** With past usage records and external factors, AI technologies can also predict future demand for library materials. This allows libraries to anticipate what their users will require, distribute resources as effectively as possible, and enhance users experience overall.

All things considered, Libraries are being transformed by AI by increasing accessibility, optimizing operations, boosting resource discoverability, and enabling libraries to provide better services to their users [17]. Libraries can adjust to the changing requirements of their communities and continue to be important information and knowledge centres in the digital age by skillfully using AI technology.

Slowness was the library's best-kept secret embrace of digital technologies and automation. From archives and audiobooks to make areas and video collections, The public believes that a library is at the forefront of technology. While claiming that anyone may access the information online, library critics refer to the actual stacks and socioeconomic divide. Instead of asserting that the library is not succeeding in digitizing, the argument emphasizes. Although librarianship is quick to refute this claim, the field finds it difficult to acknowledge its shortcomings in light of the advancement of digital technology. In the past, the library has been hesitant to adapt, often delaying responding to a new trend until a certain technology has reached market saturation. The library will embrace the usage of a technology after its users have been exposed to it in a variety of settings [18]. The potential of these two disciplines, which have been popularised by science fiction, is just now becoming apparent. Different conceptions of what artificial intelligence (AI) is and what qualifies as AI hamper this effort. Although it is often understood that artificial intelligence Artificial intellect (AI) is computer software that mimics human intellect. really much more than that. AI is now widely used in daily life because to technologies like The Internet of Things, satellites, autonomous automobiles, and—perhaps most obviously—Google.

1.2 AI-POWERED RECOMMENDATION SYSTEMS IN LIBRARIES

Recommendation engines driven by AI are changing how libraries work today. Libraries are now using these systems to watch what people do, what they like, and what books and resources they have. By knowing these things, the systems give custom suggestions, which makes the whole library visit better and helps people find what they're looking for quick. They do this by using advanced algorithms and machine learning.

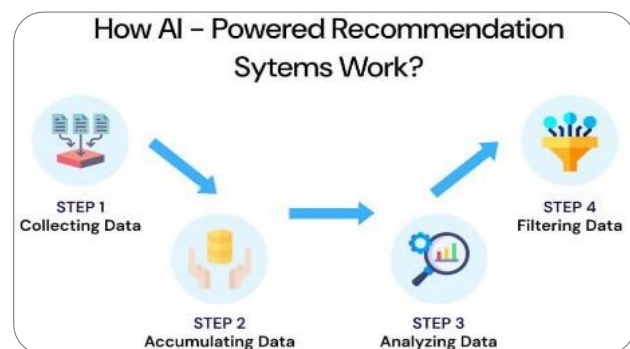


Figure 2 Ai powered recommendation system

- **Personalization and user engagement:** Recommendation systems look at what people do and like using innovative techniques like text-based and collective filtering. Librarians can then make the library experience better by getting to know what each user likes, which will probably get people to use the library more.
- **Content-based filtering:** Recommendation systems often use filtering by content to provide suggestions. These systems look at what you've liked before and then advise similar items. Nine AI helpers check out the item's content and match it to your past preferences to give you better ideas.

- **Collaborative filtering:** Okay, so collaborative filtering gives suggestions by checking out what users do and like. AI finds similar users and suggests things that those users liked.
- **Hybrid recommendation systems:** So, library recommendation systems often mix content-based and collaborative filtering. This combo takes the good bits from each approach to give you better, more varied recommendations that fit what you like.
- **Improved resource discovery:** So, library recommendation systems often mix content-based and collaborative filtering. This combo takes the strong points from both methods to give users better, more diverse, and personal suggestions.
- **User feedback integration:** AI usually uses what you put in to get better at giving advice as time goes on. So, librarians can figure out if people dig the stuff that's suggested, and the system can tweak itself to get even better later.
- **Ethical considerations:** Librarians using AI to suggest books should consider ethics. They should be upfront about how the suggestions are made and try to avoid biases creeping into the AI. Reducing bias helps include everyone, and being open builds trust with users.
- **Real-time assistance for patrons:** Helping customers out in real time means giving them quick, interactive support or info, usually when they're dealing with customer service or need help. This type of assistance employs various tech and means to communicate so people are able to receive help quickly when they need it.

Libraries have traditionally been knowledge bases, giving access to information resources and aiding research and pedagogy efforts. However, with the digital era changing the way individuals perceive and search for information, libraries need to radically change their operating models and service provision. In response to these changes, the concept of "smart libraries" emerged, leveraging advanced technology to deliver dynamic, stimulating, and productive learning spaces [19]. Computational methods, Internet of Things (IoT) technology, and artificial intelligence (AI) platforms They're all used in sophisticated libraries to maximize resource consumption, enhance customer satisfaction, and automate processes. Almost 45% of higher institutions globally have made use of smart technology, based on recent statistics, and projections show that the figure will have a compound annual growth rate (CAGR) of 12.8% from 2023 to 2030. [20].

Significant of the study

The present study, "Next-Generation Collection Strategies: Investigating the Role of Artificial Intelligence in Library Science," is significant in that it highlights Artificial intelligence's transformative potential in reframing how libraries create, curate, and disseminate their collections. Old-fashioned collection production methods are no longer sufficient in offering timely access to relevant information in view of the fast development of digital materials and evolving user needs. Libraries can enhance decision-making, personalize resource recommendations, and optimize acquisition strategies with the help of AI-based tools like natural language processing, machine learning, and predictive analytics. As it helps bring insights on how AI can enhance user experience, increase efficiency, and support evidence-based collection management, this research is important for researchers, library staff, and policymakers. It also addresses problems such as resource shortages, information overload, and the demand for innovative solutions in the information era, which ultimately contributes to libraries being relevant and sustainable in the society of knowledge.

Problem Statement

While libraries have always been critical to the management and sharing of information, traditional collecting strategies have

been severely challenged by the runaway growth of digital content, demands for instant access from users, and the emergence of big data. Traditional collection organisation, cataloging, and maintenance methods are frequently time-consuming, manual, and lack a high degree of flexibility in responding to evolving information needs. Libraries find it challenging to uphold accuracy, personalization, and effectiveness in handling resources due to increasing digital material complexity. Additionally, being able to offer relevant and user-centric services is impaired by the lack of automation and knowledge-based decision-making features in most library systems. These concerns illustrate the significance of exploring innovative, technology-based answers that can transform gathering strategies and enhance library science's overall effectiveness in a digital age.

Contribution of the Study

This research adds to the body of knowledge on AI in libraries by investigating how AI-powered resources can change cataloguing practice. Of specific interest is how AI can improve cataloguing, automate metadata creation, optimize the buying of resources, predict user preferences, and offer personalized recommendations for library users. The study provides insight into how AI can reconcile the disparity between conventional library procedures and the requirements of today's digital age by focusing on the next generation methods. The study also offers a model for AI integration in libraries management systems, which will facilitate academic institutions, librarians, and policymakers to adopt data-informed, user-centric, and sustainable acquisition practices.

2. REVIEW OF LITERATURE

[21] Modern technical innovations include AI. AI may transform the greatest digital services and is already used in libraries. The goal of this project is to demonstrate AI in libraries. Some research has tackled this topic, but only for a few applications. The link between AI and libraries is evident, but this session will address some of the remaining questions about AI knowledge and library services. Before adopting AI in library services, our research will assist academics, librarians, and policymakers address these concerns. Content analysis is used in this qualitative research. We searched the research on "smart libraries" and "artificial intelligence" latest breakthroughs. We read extensively about "ambient intelligence," "data mining," "electronic resource management," "Internet of Things," "smart technologies," and "artificial intelligence." This article covers AI in library services' merits and drawbacks and possible remedies. This study found that AI might benefit library services. Insufficient money, librarians' reluctance to adopt AI, and a lack of technical expertise make AI adoption in libraries difficult. Results show that libraries may advance faster using AI when used for their jobs. Additionally, this analysis suggests some free applications. This study may interest academics, librarians, lawmakers, researchers, and the government since it gives a nationwide overview of library technology use. This investigation may illuminate the present state of this technology and its potential to improve information center and library services. Library employees will be able to apply AI into their daily tasks thanks to this research. speeding improving library operations. This research attempts to equip librarians with the tools they need to deploy AI in libraries. AI-powered library services will pave the road for its future use.

[22] Studies in machine learning and artificial intelligence is being conducted by academics, researchers, and information professionals due to the increasing significance of these new technologies. Gathering the results of empirical studies that investigate potential AI and ML applications in libraries is the primary motivation for this comprehensive literature analysis. To achieve the goals of the research, a review of the literature

conducted systematically using the initial criteria. Scopus, LISA, Web of Science, and LISTA were the databases from which we retrieved our data. One hundred and twenty-two articles were reviewed and assessed to give a synopsis of the most popular library-related AI and ML topics and approaches, using a rigorous and well-known selection process. Currently, most AI and ML research pertinent to the LIS discipline appears to be theoretical, according to the results. However, there are academics who have opted to concentrate on specific projects or case studies. Researchers, librarians, and school administrators will all benefit from this study's comprehensive overview of library AI and ML applications. They may utilize this information to prepare for future advancements and implement strategies that are more tech-focused.

[23] This study emphasises the important relationship between library and artificial intelligence (AI) by looking at how affects library services. Few studies have examined the impact on academic researchers and use awareness, notwithstanding earlier study. To enhance the provision of services in the information age, the study intends to assist policy makers, librarians, and academics in addressing these concerns prior to implementing AI in library services.

[24] The study investigates how Malaysian libraries might enhance their content marketing strategies by implementing artificial intelligence (AI). With more than 75% of libraries investigating AI technologies, user engagement has increased by 45%. Data privacy and digital inequality are issues that must be addressed, though. The study examines how AI affects user adoption and happiness using the Technology Acceptance Model and Personalisation Theory. It suggests making calculated investments in personnel development, ethical standards, and AI infrastructure.

[25] The study examines how Library services are being transformed by artificial intelligence (AI), which improves user experiences, operational effectiveness, and information availability. Applications such as AI-powered virtual assistants, personalised recommendation systems, automated cataloguing, and predictive analytics for collection management are highlighted. The digital divide and However, integration raises ethical questions. In order to realize AI's full potential, the research suggests inclusive service models, ethical AI development, and further collaboration between libraries and AI researchers.

[26] The research explores how social science research is being transformed due to the meeting point of library and information science (LIS) with artificial intelligence (AI). AI-driven innovations are increasing information retrieval, database organising and curating, and pattern detection in them. Librarians might focus on offering personalised services by leveraging AI to automate procedures such as cataloguing, classification, and preservation. Additionally, AI may develop customized recommendation systems that exploit a user's learning history and interests to suggest appropriate materials. which results in more comprehensive and insightful social science analysis.

[27] summarized the literature regarding artificial intelligence (AI) use in libraries for role that these applications play in library functions. Employing the Scopus database, the research methodology discovered 66 related papers in artificial intelligence. This page gave the overall conclusions and summaries of the 65 articles that were analyzed after duplicates were removed and filters had been used. Researchers interested in researching AI usage in libraries can use the information provided here as a source.

[29] explored how AI impacts library functions, specifically on information management. AI enhances resource allocation, enhanced search, and accelerates cataloging. It impacts user experiences as well by enabling decision-making based on data

and mitigating information overload problems. The proposed approach simplifies interactions, detects routes within the library, automates tasks for both the librarians and the users, and simplifies searches of books. The research underscored the importance of understanding AI technologies for the development of intelligent systems and how AI can revolutionize libraries by developing an information ecosystem that has evolved to become responsive, efficient, and accessible.

[30] discussed potential future developments, provides a summary of the AI applications being used in libraries today, and discusses the challenges and ethical problems involved with integrating AI into library systems. Using a mixed-methods approach, the study integrates qualitative information from expert interviews and literature reviews with quantitative data from a survey of 200 library employee's interviews. The results showed that while people are becoming more aware of AI applications, such as conversational search engines, AI assistants, automated classification, and recommendation engines, real implementation was still restricted because of issues including insufficient training, financial limitations, and moral dilemmas. Compared to public or special libraries, academic libraries had a somewhat greater rate of AI integration. It ends with practical suggestions, such as user-driven development tactics, cross-sector partnerships, the creation of ethical AI frameworks, and focused training initiatives.

[31] This research explored the impacts of personalized recommendations driven by artificial intelligence (AI-PPRs) on TikTok (Douyin in China) users' engagement, browser habits, and purchase intents in order to fully comprehend the effects of these suggestions on users' happiness and purchase intent along with any potential privacy concerns. In order to investigate Douyin users' experiences and perceptions of AI-PPRs based on the stimulus-organism-response model and the theory of expectation value, the study used qualitative methods via interviews. Through live streaming and captivating short movies, Douyin's AI-PPRs which include finding new products for the pleasure experience improve user engagement by cutting down on search time and raising satisfaction. However, when customisation has seen as invasive, it may cause unpleasant feelings and avoidance behaviours, raising privacy problems. While technical difficulties like network problems might have had a detrimental effect on user experience, cultural context and the time of recommendations can affect receptiveness. Since inadequate or inappropriate material might result in unfavourable opinions and disengagement, content quality was essential. Genuine influencer endorsements and those from reliable sources are more palatable. "Douyin Monthly Payment" has become one of the innovative payment options that encourages client loyalty. Maintaining customer engagement and loyalty in AI-PPRs and maintaining trust depend on striking a balance between customisation and privacy.

This chapter [32] investigated the use of AI, focusing on recommendation and knowledge discovery systems. Suggestion AI-powered engines provide personalized recommendations, boosting user engagement and streamlining the process of finding information. AI-driven resource identification tools help with trend analysis and resource summaries by drawing insightful conclusions from large datasets. The user-centered, efficient, and enriching nature of the library experience was enhanced by the integration of various AI-powered technologies. This chapter demonstrated how AI-driven search and recommendations may turn libraries into flexible, dynamic organizations at the center of the dissemination of information. In the rapidly developing digital world, libraries must manage massive amounts of material while also providing users with excellent resource discovery. The management of libraries has been transformed dramatically because artificial intelligence (AI) has been used.

[33] Examining how AI-powered recommendations affect customer behavior in online marketplaces was the aim of this study. It concerned hybrid recommender systems involving natural language processing methods and collaborative filtering approaches. The work develops and examines these systems based on the Kaggle dataset for Amazon sales, measuring their performance in terms of visual attractiveness, diversity, relevance, and satisfaction. Through an examination of their principles, operation, in terms of effect on client loyalty, the research also considered the wider implications of AI-driven recommendations for customer engagement. The research also considered ethical issues and identifies key factors that lead to their effectiveness. Overall, this research provides a comprehensive examination of AI-driven recommender systems in e-commerce platforms.

[34] investigated the ways through which library systems can be integrated with artificial intelligence (AI), highlighting the ways through which it can improve services through automation, personalization, and improved access to information. NLP enriched search interfaces and user interaction, while machine learning and deep learning automate categorization and retrieval processes. Computer vision captures and stores library materials digitally, while knowledge representation and reasoning structure digital information. In addition to solving ethical problems such as maximizing algorithmic fairness and ensuring privacy, the chapter emphasizes the necessity of accountability and transparency. All things being equal, AI technologies could potentially revolutionize traditional library systems, boosting user interaction and operational efficiency.

AI has transformed library services by [35] promoting inclusive user experiences and allowing personalised distribution. Libraries may enhance user engagement and information delivery by using technology such as recommender systems, machine learning, and natural language processing. By analysing user behaviour, machine learning models proposed resources in a personalised way. Information overload and linguistic obstacles are reduced via natural language processing. Recommender systems used content-based and collaborative filtering strategies to recommend relevant resources. Chatbots and digital assistants driven by AI provide real-time assistance, simplifying questions guaranteeing accessibility for those with impairments. These resources improved inclusion for people with visual and auditory impairments when linked with assistive technology. AI-powered solutions break down language, cultural, and geographic obstacles to provide library services to underprivileged populations.

2.1 Research Gap

Despite the fact that a growing amount of research has examined how artificial intelligence (AI) was changing library services, the majority of these studies are still fragmented, either concentrating on particular contexts like academic libraries in Malaysia or Nigeria or on particular tools like recommender systems, cataloguing automation, or virtual assistants. Instead of providing empirical insights into real-world implementation, user uptake, and long-term sustainability, the majority of the research being done now is descriptive or conceptual in personality. Furthermore, while comprehensive ways to tackle these obstacles are not well established, issues including budgetary limitations, librarians' reluctance to accept new technology, a lack of technical skills, and ethical considerations like data privacy and digital inequality are recognised. Few studies incorporate cross-disciplinary perspectives or offer comparative analyses of how various library systems academic, public, and special can adapt AI for collection strategies in varying socioeconomic and cultural contexts, even though earlier works emphasise AI's potential to improve personalisation, efficiency, and inclusivity. Therefore,

there is a deficiency of methodical, application-focused, and cross-context research that not only recognises the promise of AI but also tackles its obstacles by developing workable frameworks, regulations, and implementation plans specifically designed for next-generation library collection techniques.

3. METHODOLOGY

3.1 Research design

A quantitative research approach was used in the study to look at the artificial intelligence in library science. Data was collected from 384 respondents using a structured online questionnaire. The validated questionnaire used to gather the data consisted of Likert-scale questions. "Statistical software for the social sciences," or SPSS, was used to investigate the information.

3.2 Conceptual framework

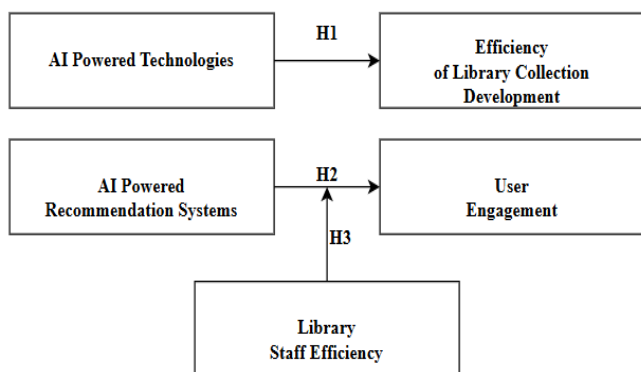


Figure 3 Conceptual framework

3.3 Objectives

- To investigate how AI-powered technologies affect library development efficiency.
- To explore how AI-powered recommendation systems affect user engagement while taking library staff productivity into account as a mediating factor.
- To evaluate how user pleasure, engagement, and general library patronage are affected by AI-powered technology development initiatives.

3.4 Sample selection

In order to create a representative dataset for analysis, the research used a sample size of 384 individuals. To investigate artificial intelligence in the field of libraries, the stratified random sampling technique was used.

3.5 Data collection

This study used a quantitative methodology, ensuring accuracy and reliability via the use of systematic data collection methodologies. A standardized several Likert-scale observations survey was employed as the primary instrument for gathering data in order to evaluate the artificial intelligence in library science. Important questionnaire elements are AI Powered Technologies, Efficiency of Library Collection Development, AI Powered Recommendation Systems, User Engagement, Library Staff Efficiency. Google Forms was used to collect 384 legitimate replies. Secondary data from published studies, government websites, and institutional records will be used to augment the original data.

3.6 Measures

A systematic questionnaire has been used to collect data. A five-point Likert scale (strongly disagree with strongly agree) has been used to develop the questionnaire, which asks users to rate their thoughts on the many research subjects being investigated.

Both closed-ended and open-ended questions are included in the questionnaire. Thoroughly considered questions were developed to collect relevant data on the factors under investigation. The survey comprises five different kinds of respondents, and a unique questionnaire has been created for each. The factors and number of items taken into consideration for the research are shown in the table below.

S. No	Variable Name	No. Items
1	AI Powered Technologies	5
2	Efficiency of Library Collection Development	5
3	AI Powered Recommendation Systems	5
4	User Engagement	5
5	Library Staff Efficiency	5

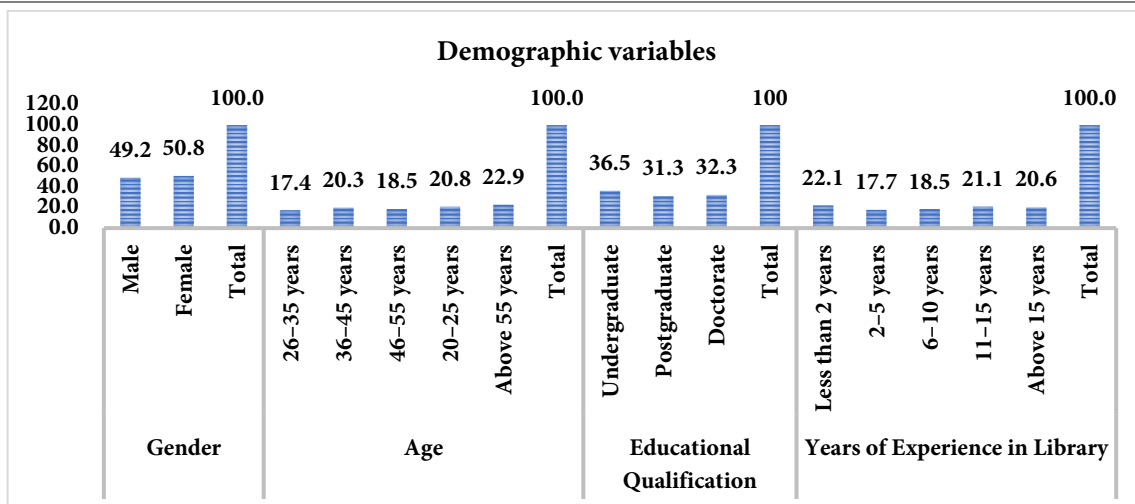
4. RESULTS

The study defines its objectives by investigating how AI-driven technologies might improve the production of library collections and how AI-based systems for recommendation affect user interaction, with library staff efficiency acting as a mediating variable. The results were analysed utilising a quantitative research design to achieve these objectives. Demographic profiling was initially performed to comprehend the respondents' backgrounds. The variables' validity and reliability have been assessed using Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Characteristic statistics were utilised to assess views regarding the constructs, subsequently followed by hypothesis testing by structural equation modeling (SEM) application. Confirmatory Factor Analysis is referred to as CFA. Various indicators of model fit were used to validate the measurement and structural models, hence confirming the accuracy and resilience of the findings.

4.1 Demographic variables

Table 1 Demographic variables

		Frequency	Percentage
Gender	Male	189	49.2
	Female	195	50.8
	Total	384	100.0
Age	26–35 years	67	17.4
	36–45 years	78	20.3
	46–55 years	71	18.5
	20–25 years	80	20.8
	Above 55 years	88	22.9
	Total	384	100.0
Educational Qualification	Undergraduate	140	36.5
	Postgraduate	120	31.3
	Doctorate	124	32.3
	Total	384	100
Years of Experience in Library	Less than 2 years	85	22.1
	2–5 years	68	17.7
	6–10 years	71	18.5
	11–15 years	81	21.1
	Above 15 years	79	20.6
	Total	384	100.0



With 49.2% of the participants being men and 50.8% being women, the social profile of the respondents ($N = 384$) shows a virtually equal gender distribution. The age bracket that is most prevalent is above 55 years (22.9%), followed closely by 20–25 years (20.8%) and 36–45 years (20.3%), demonstrating presence among both younger and older demographics. The educational qualifications reveal a varied composition, with 36.5% of respondents being undergraduates, 31.3% postgraduates, and 32.3% possessing doctorates, indicating a highly qualified respondent pool. Concerning library work experience, 22.1% has less than 2 years, while 21.1% and 20.6% have 11–15 years and over 15 years, respectively, indicating a balanced distribution of early-career and seasoned workers. The sample exhibits diversity in terms of gender, age, education, and professional experience. **Table 2** Validity and Reliability

Constructs	Cronbach's Alpha	Composite Reliability	AVE
AI Powered Technologies	0.879	0.74	0.707
Efficiency of Library Collection Development	0.897	0.744	0.714
AI Powered Recommendation Systems	0.892	0.74	0.707
User Engagement	0.891	0.739	0.705
Library Staff Efficiency	0.86	0.705	0.648

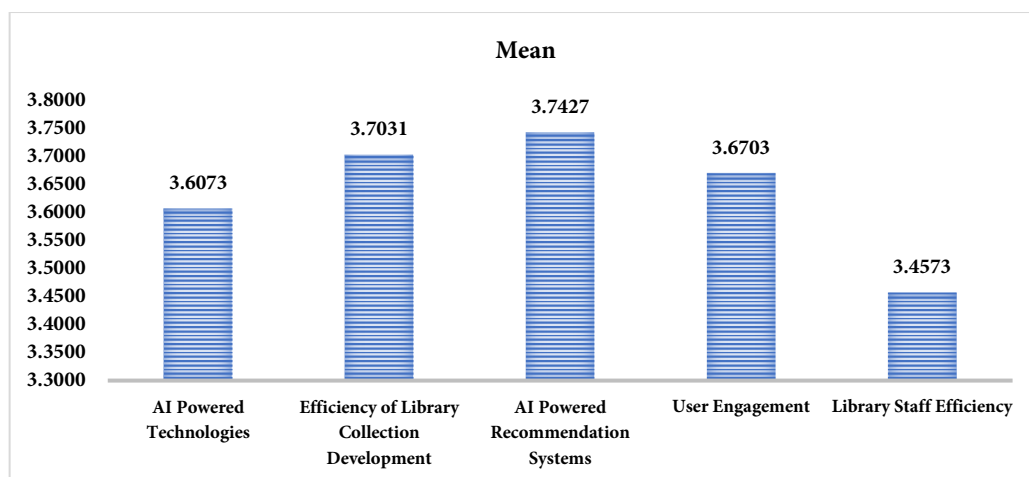
The research constructs have great internal consistency and construct dependability, according to the reliability and convergent validity examination. The assessment items show excellent consistency, as shown by Cronbach's alpha values for all constructs ranging from 0.86 to 0.897, which are higher than the usually recognized threshold of 0.70. The constructs are reliable, as shown by the composite reliability (CR) ratings, which range

from 0.705 to 0.744. Enough convergent validity and that the constructs explain a substantial portion of the variation in their respective indicators are shown by the average variance extracted (AVE) values, which range from 0.648 to 0.714 and are over the suggested criterion of 0.50. These findings demonstrate that the measurement model is accurate and valid for subsequent structural analysis.

Table 3 Mean and standard deviation

Variables	Mean	Std. Deviation
AI Powered Technologies	3.6073	0.78334
Efficiency of Library Collection Development	3.7031	0.79001
AI Powered Recommendation Systems	3.7427	0.79163
User Engagement	3.6703	0.83498
Library Staff Efficiency	3.4573	0.71511

The descriptive statistics of the study variables reveal that respondents typically possess a relatively favourable impression of the constructs examined. AI-powered recommendation systems received the highest mean score of 3.7427 ($SD = 0.7916$), showing a significant recognition of their function in library operations. The effectiveness of library collection creation (Mean = 3.7031, $SD = 0.7900$) and user engagement (Mean = 3.6703, $SD = 0.8350$) are closely ranked, indicating that respondents see both successful collection management and active involvement as vital components of library operation. AI-powered technologies achieved a mean score of 3.6073 ($SD = 0.7833$), signifying moderate adoption or consensus. The efficiency of library staff recorded a mean of 3.4573 ($SD = 0.7151$), which, despite being above the midpoint, indicates potential for enhancement. The statistics indicate a favourable yet diverse assessment of AI integration and operational effectiveness in the library context



5. Hypothesis

H1: AI-Powered Technologies have a positive effect on the Efficiency of Library Collection Development.

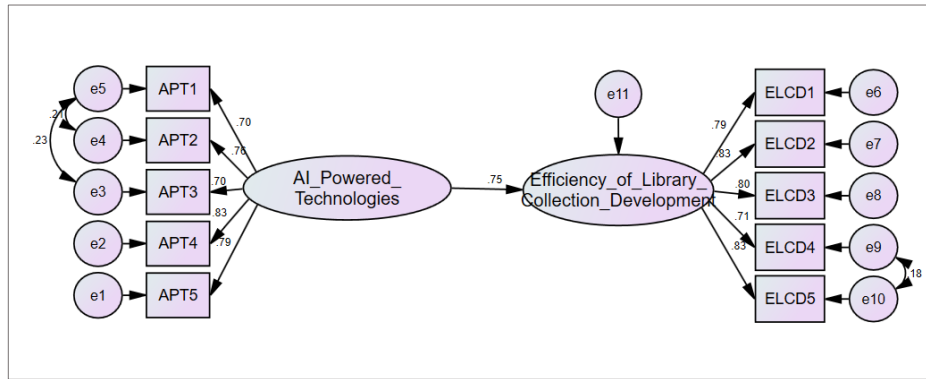


Table 4 Regression Weights: (Group number 1 - Default model)

Path			Standardized Estimate	S.E.	C.R.	P
AI-Powered Technologies	<-- -	Efficiency of Library Collection Development	0.746	0.059	12.358	***

The analysis of the proposed relationship (H1) reveals that AI-driven technologies significantly enhance the efficiency of library collection development. The standardised estimate of 0.746 indicates a significant effect, suggesting that an increase in the use or adoption of AI-powered technologies enhances the efficiency of library collection development. The standard error of 0.059

signifies a precise estimation of this effect, whereas the critical ratio (C.R.) of 12.358 denotes a very significant finding. The statistical significance of this link is shown by the provided p-value of *** at conventional levels, hence supporting H1 and showing that AI-powered technologies are integral to improving library collection building procedures.

Table 5 Model fit Summery

CMIN	DF	CMIN/DF	GFI	NFI	RFI	IFI	CFI	RMR	RMSEA
59.025	31	1.904	.969	.974	.963	.988	.988	.024	.049

The information provided shows the outcomes of a Confirmatory Factor Analysis (CFA) or Structural Equation Modelling (SEM) goodness-of-fit evaluation. Chi-square value (CMIN) is 59.025 with 31 degrees of freedom, resulting in a CMIN/DF ratio of 1.904, which signifies a satisfactory fit as values below 3 are typically deemed acceptable. The model's sufficiency is supported by the fit indices, which show that it fits the data well.

The GFI, NFI, RFI, IFI, and CFI all above the necessary cutoff of 0.90. There is a close match between the Root Mean Square Residual (RMR) of 0.024 and the Root Mean Square Error of Approximation (RMSEA) of 0.049, as values below 0.05 are considered good. Collectively, these indices indicate if the data is well and strongly fitted by the equation.

H2: AI-Powered Recommendation Systems positively influence User Engagement.

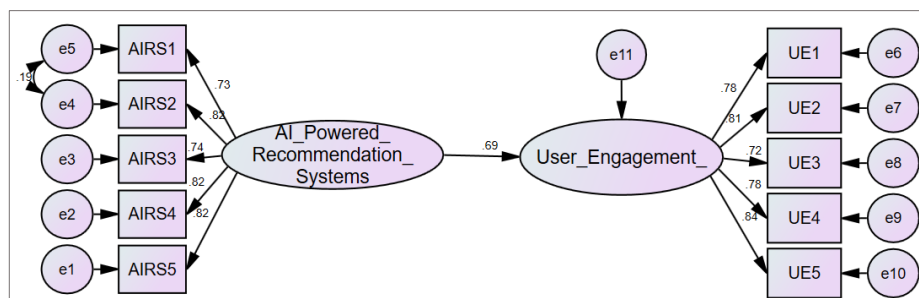


Table 6 Regression Weights: (Group number 1 - Default model)

Path			Standardized Estimate	S.E.	C.R.	P
User Engagement	<---	AI Powered Recommendation Systems	0.693	0.058	11.827	***

The findings show a robust and noteworthy positive correlation between AI-driven recommendation systems and user engagement. The standardised estimate of 0.693 indicates that when the efficacy of AI-powered recommendation systems improves, user engagement significantly increases. The standard error (S.E.) of 0.058 signifies a minimal degree of fluctuation in the estimate, demonstrating measurement precision. The critical

ratio (C.R.) of 11.827 significantly exceeds the traditional threshold of 1.96 for significance at the 0.05 threshold, with the associated p-value being highly significant (***), affirming the statistical stability of this relationship. These data substantiate the idea that AI-driven recommendation systems enhance user engagement.

Table 7 Model fit Summery

CMIN	DF	CMIN/DF	GFI	NFI	RFI	IFI	CFI	RMR	RMSEA
76.392	33	2.315	.963	.967	.955	.981	.981	.029	.059

A generally favorable fit of the proposed structural equation model is shown by the model fit indices. With 33 degrees of freedom and a Chi-square value (CMIN) of 76.392, the CMIN/DF ratio is 2.315, below the generally accepted cutoff of 3, suggesting an acceptable fit. The comparative fit indices NFI (0.967), RFI (0.955), IFI (0.981), and CFI (0.981) all above the necessary cutoff of 0.90, indicating a strong match between the suggested model

and the observed data, and the goodness-of-fit index (GFI) is 0.963. The model shows an adequate to excellent fit, as shown by the root mean square residual (RMR) of 0.029 and the root mean square error of approximation (RMSEA) of 0.059, both of which fall within acceptable standards. All together, these indices show that the equation is well-defined and successfully depicts the relationships between the variables.

H3: Library Staff Efficiency mediates the relationship between AI-Powered Recommendation Systems and User Engagement.

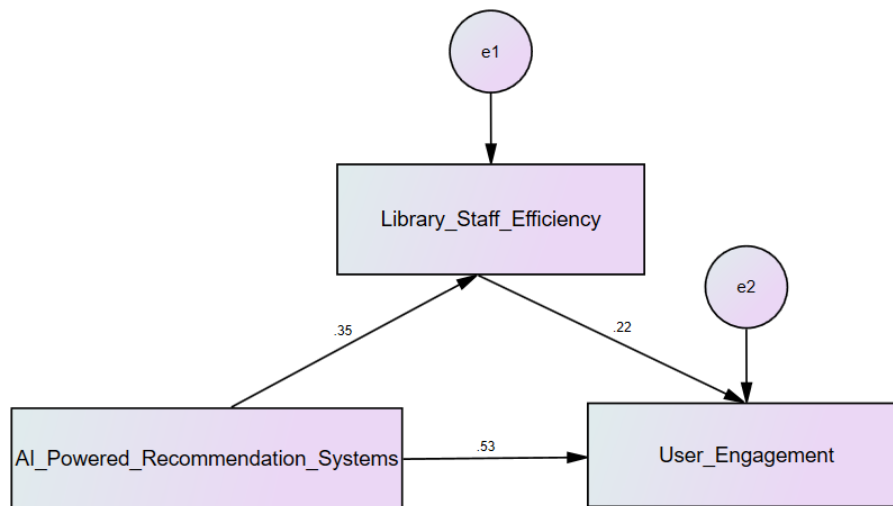


Table 8 Regression Weights: (Group number 1 - Default model)

Path			Standardized Estimate	S.E.	C.R.	P
Library Staff Efficiency	<---	AI Powered Recommendation Systems	0.351	0.043	7.336	***
User Engagement	<---	AI Powered Recommendation Systems	0.529	0.044	12.624	***
User Engagement	<---	Library Staff Efficiency	0.219	0.049	5.223	***

The structural equation modelling (SEM) findings demonstrate a significant positive correlation between AI-driven recommendation systems and both library staff productivity and user engagement. AI-driven recommendation systems yield a standardised estimate of 0.351 regarding library staff efficiency (S.E. = 0.043, C.R. = 7.336, $p < 0.001$), indicating that implementation of AI tools significantly improves staff performance in library management. Furthermore, AI-driven recommendation systems significantly impact user engagement, with a standardised estimate of 0.529 (S.E. = 0.044, C.R. = 12.624, $p < 0.001$), indicating an effective direct effect on user interaction with library resources. Moreover, the efficiency of library personnel significantly influences user engagement (standardised estimate = 0.219, S.E. = 0.049, C.R. = 5.223, $p < 0.001$), hence

substantiating mediating function of staff efficiency in the correlation between AI-driven recommendation systems and user engagement. These data indicate that AI deployment directly increases user engagement and indirectly enhances it by enhancing library staff efficiency.

6. Discussion

This study highlights artificial intelligence (AI) applications in libraries include growing because it improves efficiency, accessibility, and user engagement. Instruments like chatbots, recommendation systems, and automated cataloguing have improved resource management and user contentment [36]. Nonetheless, the study highlights obstacles such as substantial implementation costs, talent deficiencies, moral challenges, and

data privacy concerns that require careful consideration. To guarantee ethical and sustainable adoption, libraries must allocate resources for staff training, enhance openness and inclusivity, and foster collaboration among professionals and policymakers.

This study focused at the growth, major contributors, the topical development of AI studies in university libraries using bibliometric analysis. The results show noteworthy trends in authorship patterns, regional contributions, publication output, and new AI applications. In addition to descriptive data, it is crucial to assess these findings in view of the study's goals, draw conclusions about their applicability, and suggest particular ideas for further study. Research demonstrates how AI is increasingly being used to improve user interactions, improve resource discovery, and automate routine library tasks. The rise in research on AI indicates that university libraries are progressively using AI to increase productivity, customise services, and facilitate digital transformation. But even with this expansion, certain fields of study are still lacking in depth [37]. AI-powered educational honesty solutions for detecting plagiarism and accessible solutions for people with disabilities, for instance, are not as well researched as chatbots and data mining. Future research possibilities are presented by these gaps. Research on AI has significantly increased since 2015, according to publication patterns, and has peaked in recent years. Multi-author articles often get more academic attention, as seen by the high impact of joint research. The necessity for greater multidisciplinary research cooperation is highlighted by this trend. To create more complex AI applications, university libraries should integrate knowledge from data analytics, computer science, and data ethics into their AI studies.

The demographic research provides a comprehensive perspective on the subject matter by demonstrating an even and diversified representation across an array of demographic factors, including gender, age, education, and professional experience. It has been established via the assessments of reliability and validity that the constructs that were used are reliable and consistent, which in turn contributes to the increased trustworthiness of the outcomes. According to the qualitative analysis's findings, respondents' opinions on artificial intelligence technologies and its applications were mostly positive, particularly recommendation systems, which are recognised as having a significant influence on user interaction and library activities. The testing hypothesis demonstrates that technologies powered by artificial intelligence provide a significant acceleration in the growth of collections, and that recommendation systems are strongly connected with improved user involvement. The mediation study reveals that the efficiency of library personnel is of utmost importance, as they act as a conduit between user interaction and systems for suggestions. This highlights dual effect artificial intelligence, which directly enhances engagement while indirectly reinforcing it via higher staff productivity. Strong theoretical and empirical validation is shown by the fact that the suggested structural models match effectively as shown by the model fit scores that were obtained from the research. Based on these results, Artificial intelligence's integration with library science results in a boost in efficiency in operations and a greater enrichment in user involvement, making it feasible to apply new collection methods that utilize both technological innovation as well as human knowledge.

7. Conclusion

Based on the research findings, the development of libraries is greatly impacted by artificial intelligence. science by making it more efficient, raising the level of user interaction, and enhancing the creation of quality collections. The age and gender profile of the individuals who took part in responding reveals a satisfactory blend of genders, age brackets, education levels, and work

experience, ensuring that a complete outlook is gained. The results of tests for validity and reliability indicate that concepts applied within the research are consistent, reliable, and apt for structural analysis based on findings. Descriptive data indicate that AI-based recommending systems and collection development practices are greatly valued. Conversely, staff efficiency, despite being viewed positively, has potential for improvement. Testing the hypothesis proves that technology driven by artificial intelligence vastly improves the process of building library collections, while recommendation systems immensely increase user engagement. Furthermore, the mediation impact of staff efficiency highlights the fact that artificial intelligence not only directly improves user engagement but also increases it by boosting staff effectiveness. The model fit indices provide further evidence that the structural model provides a reliable and accurate depiction of the interactions that occur between the components. The results of the research show that the use of AI in libraries improves collecting methods, increases user engagement, and has a major influence on operational effectiveness., therefore establishing AI as a revolutionary force in the practices of future libraries.

Reference

- [1] L. Husni and A. Armizawati, "Utilization of Artificial Intelligence in Libraries as a Form of Library Development," ... *Int. Conf. ...*, pp. 79–85, 2024, [Online]. Available: <https://proceeding-perpus.uinib.ac.id/index.php/AICIBLib/article/view/2%0Ahttps://proceeding-perpus.uinib.ac.id/index.php/AICIBLib/article/download/2/10>
- [2] N. Kranich, "Libraries, the Internet, and democracy," *Libr. Democr. cornerstones Lib.*, pp. 83–95, 2001.
- [3] D. L. Gilton, *Lifelong learning in public libraries: Principles, programs, and people*. Scarecrow Press, 2012.
- [4] A. Kaplan and M. Haenlein, "Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence," *Bus. Horiz.*, vol. 62, no. 1, pp. 15–25, 2019.
- [5] M. I. Jordan and T. M. Mitchell, "Machine learning: Trends, perspectives, and prospects," *Science (80-.)*, vol. 349, no. 6245, pp. 255–260, 2015.
- [6] M. N. Islam and H. Guangwei, "Trends and Patterns of Artificial Intelligence Research in Libraries: A Bibliometric Analysis," *SAGE Open*, vol. 15, no. 2, pp. 1–21, 2025, doi: 10.1177/21582440251327528.
- [7] P. Kumar and Jyoti, "Reshaping the library landscape: Exploring the integration of artificial intelligence in libraries," *IP Indian J. Libr. Sci. Inf. Technol.*, vol. 9, no. 1, pp. 29–36, 2024, doi: 10.18231/j.jilsit.2024.005.
- [8] E. D. Orubebe, E. A. Oloniruha, and B. D. Oladokun, "Adoption and utilization of artificial intelligence in academic libraries: Challenges and opportunities in developed and developing nations," *Int. J. Knowl. Content Dev. Technol.*, pp. 1–13, 2024.
- [9] K. A. Owolabi, N. C. Okorie, O. E. Yemi-Peters, S. O. Oyetola, T. O. Bello, and B. D. Oladokun, "Readiness of academic librarians towards the use of robotic technologies in Nigerian university libraries," *Libr. Manag.*, vol. 43, no. 3–4, pp. 296–305, 2022, doi: 10.1108/LM-11-2021-0104.
- [10] J. M. Reitz, "ODLIS Online dictionary for library and information science," 2017.
- [11] R. Article and A. Info, "Uluslararası Sosyal ve Beşeri Bilimler Dergisi International Journal of Social Sciences & Humanities," vol. 9, no. 2, pp. 59–74, 2025.
- [12] Y. Wang and T. A. Dawes, "The next generation integrated library system: A promise fulfilled," *Inf. Technol. Libr.*, vol. 31, no. 3, pp. 76–84, 2012, doi: 10.6017/ital.v31i3.1914.

- [13] A. A. Kinengyere, "Meeting: 100. Continuing Professional Development and Workplace Learning with New Professionals SIG," *Contin. Prof. Dev.*, pp. 1–16, 2009.
- [14] R. Basak, P. Paul, S. Kar, I. H. Molla, and P. Chatterjee, "The future of libraries with AI: Envisioning the evolving role of libraries in the AI era," in *AI-Assisted Library Reconstruction*, IGI Global Scientific Publishing, 2024, pp. 34–57.
- [15] A. Gasparini and H. Kautonen, "Understanding Artificial Intelligence in Research Libraries: An Extensive Literature Review," *Lib. Q.*, vol. 32, no. 1, pp. 1–36, 2022, doi: 10.53377/lq.10934.
- [16] M. Garnier, M. Cussac, C. Delaune, C. Espy, and L. Papon-Vidal, "The Pivotal Role of Libraries in Sustainable AI Development," *Can. J. Inf. Libr. Sci.*, vol. 47, no. 2, pp. 137–149, 2024, doi: 10.5206/cjils-rcsib.v47i2.17699.
- [17] Chandramani Kailash Gajbhiye, "Impact of Artificial Intelligence (AI) in Library Services," *Int. J. Multidiscip. Res.*, vol. 6, no. 3, pp. 1–13, 2024, doi: 10.36948/ijfmr.2024.v06i03.22452.
- [18] A. Wheatley and S. Hervieux, "Artificial intelligence in academic libraries: An environmental scan," *Inf. Serv. Use*, vol. 39, no. 4, pp. 347–356, 2020, doi: 10.3233/ISU-190065.
- [19] B. Ram, A. Kumar, and S. K. Pal, "Applications of the internet of things in library and data privacy," *IP Indian J. Libr. Sci. Inf. Technol.*, vol. 8, no. 1, pp. 14–19, 2023.
- [20] D. M. S. G. Rathod, "The Rise of Smart Libraries: Integrating IoT, Cloud Services, and AI for Next-Gen Learning Spaces," *Int. J. Res. Libr. Sci.*, vol. 11, no. 2, pp. 211–226, 2025, doi: 10.26761/ijrls.11.2.2025.1883.
- [21] S. K. Jha, "Application of artificial intelligence in libraries and information centers services: prospects and challenges," *Libr. hi tech news*, vol. 40, no. 7, pp. 1–5, 2023.
- [22] R. K. Das and M. S. U. Islam, "Application of artificial intelligence and machine learning in libraries: a systematic review," *arXiv Prepr. arXiv2112.04573*, 2021.
- [23] M. K., "A Study on Impact of Artificial Intelligence (AI) on Library Services," *Int. J. Res. Libr. Sci.*, vol. 9, no. 4, pp. 189–199, 2023, doi: 10.26761/ijrls.9.4.2023.1696.
- [24] N. A. Aqilah Mohd Sapri, A. N. Zanol Rashid, and W. A. M. Ahmad Tarmizi, "Leveraging AI for Effective Content Marketing in Libraries: Maximizing User Engagement," *Int. J. Res. Innov. Soc. Sci.*, vol. VIII, no. IX, pp. 3510–3521, 2024, doi: 10.47772/ijriss.2024.8090293.
- [25] S. N. Sathesh, V. A. Rinsey Antony, S. Anantharaman, and R. C. Ashraf, "Artificial Intelligence in Library Services: Enhancing Access, Operational Efficiency, and User Experience," *Libr. Prog. Int.*, vol. 44, no. 3, pp. 5838–5843, 2024.
- [26] D. Kamal Gulati and B. Unhelkar, "The Future of Social Sciences Research: AI-Driven Innovations in Library and Information Science," *Libr. Prog. Int.*, vol. 44, no. 2, pp. 422–428, 2024.
- [27] A. Subaveerapandiyan, "DigitalCommons @ University of Nebraska - Lincoln Application of Artificial Intelligence (AI) In Libraries and Its Impact on Library Operations Review," no. August 2023, pp. 6–24, 2023, doi: 10.6084/m9.figshare.22573345.v1.
- [28] A. A. Adewojo, O. B. Amzat, and H. S. Abiola, "AI-powered libraries: enhancing user experience and efficiency in Nigerian knowledge repositories," *Libr. Hi Tech News*, vol. 42, no. 2, pp. 12–16, Dec. 2024, doi: 10.1108/LHTN-08-2024-0142.
- [29] D. P. SK Kannaujia, PK Verma, SK Verma, *AI-Powered Revolution: Automating InformationManagement in Libraries*. 2024.
- [30] D. Mondal, "AI Powered Libraries: Charting the Future of Information Services," 2025.
- [31] L. Ding, G. Antonucci, and M. Venditti, "Unveiling user responses to AI-powered personalised recommendations: a qualitative study of consumer engagement dynamics on Douyin," *Qual. Mark. Res. An Int. J.*, vol. 28, no. 2, pp. 234–255, Dec. 2024, doi: 10.1108/QMR-11-2023-0151.
- [32] R. Sivasankari, S. Suriya, S. Sindhu, J. S. Devi, and J. Dhilipan, "AI-powered recommendation systems and resource discovery for library management," in *Applications of artificial intelligence in libraries*, IGI Global Scientific Publishing, 2024, pp. 223–244.
- [33] Erdal Ozelik, "Analysing the Role of AI-powered Recommender Systems in Enhancing Customer Engagement in Online Marketplaces: Developing A Product Recommendation System," pp. 1–23, 2024.
- [34] P. Meesad and A. Mingkhwan, "AI-Powered Smart Digital Libraries BT - Libraries in Transformation: Navigating to AI-Powered Libraries," P. Meesad and A. Mingkhwan, Eds., Cham: Springer Nature Switzerland, 2024, pp. 391–428. doi: 10.1007/978-3-031-69216-1_10.
- [35] Ugochukwu Francis Ikwanusi, Peter Adeyemo Adepoju, and Chinekwu Somtochukwu Odionu, "AI-driven solutions for personalized knowledge dissemination and inclusive library user experiences," *Int. J. Eng. Res. Updat.*, vol. 4, no. 2, pp. 052–062, 2023, doi: 10.53430/ijeru.2023.4.2.0023.
- [36] R. Sundar M, P. L. R. M. – Ece, and D. K. Meena, "Role of Artificial Intelligence in Modern Education," vol. 4, pp. 396–410, 2025, doi: 10.51767/ic250444.
- [37] M. N. Islam *et al.*, "Application of artificial intelligence in academic libraries: a bibliometric analysis and knowledge mapping," *Discov. Artif. Intell.*, vol. 5, no. 1, 2025, doi: 10.1007/s44163-025-00295-9.



Book review

Biomedical Textiles: Introduction and Applications

Edited by Dr. Mohd Yusuf and Dr. Shumaila Kiran, published by Jenny Stanford Publishing, a co-publisher of the esteemed Taylor and Francis, 2025, Vol. 1

Shafat Ahmad Khan 

SBAS, Galgotias University, Greater Noida, Uttar Pradesh 203201 India



Paper History: Received: 01-09-2025 | Revised: 25-11-2025 | Accepted: 01-12-2025 | Published: 11-12-2025

The present volume, *Biomedical Textiles: Introduction and Applications*, extends this traditional field into the rapidly expanding domain of medical science. The book offers a comprehensive introduction to fibrous textile structures—both synthetic and natural—designed for use within biological environments, either internally or externally, as medical or care devices to enhance health, hygiene, and therapeutic outcomes.

A major strength of this volume lies in its clear articulation of how the structural adaptability and mechanical flexibility of textiles can be leveraged for modern healthcare applications. The contributors emphasize that the next generation of biomedical textiles must exhibit not only biocompatibility but also tunable shape-transformation capabilities, allowing them to be inserted through minimally invasive delivery systems such as catheters, and subsequently expand or function effectively within the body. The text presents these advanced concepts with clarity, integrating engineering principles with clinical perspectives.

The book is organized into well-structured sections that progress logically from basic textile science to sophisticated biomedical applications. Early chapters provide a lucid overview of fiber chemistry, surface modification techniques, and structural design for biocompatibility, while later chapters explore applications in wound healing, vascular grafts, drug delivery systems, and tissue engineering scaffolds. Particularly noteworthy are the discussions on the mechanical performance of fibers under physiological conditions and the influence of material properties on tissue response.

What makes this volume especially valuable is its interdisciplinary approach? The editors have succeeded in bringing together research findings from materials science, biotechnology, and clinical medicine, enabling a coherent understanding of how textile innovations are driving advancements in healthcare. The chapters are well referenced and supplemented by recent research data, making the book both authoritative and accessible to graduate students and early-career researchers entering this field.

In addition to its academic merits, *Biomedical Textiles: Introduction and Applications* provides insight into industrial trends and future research directions. It highlights the importance of developing smart and responsive textiles capable of interacting with biological systems, a topic of great relevance to current scientific and medical innovation.

In addition, this book is hopefully an important contribution to the literature on biomedical materials. It will also serve as an essential reference for scientists, engineers, and clinicians engaged in the development of medical devices and healthcare technologies based on textile structures. For newcomers, it offers a systematic entry point into the complexities of textile-based biomaterials; for experienced professionals, it provides a well-curated overview of contemporary progress and future challenges.

* Corresponding Author:

✉ shafatahmad.khan@galgotiasuniversity.edu.in (S. A. Khan)

 <https://doi.org/10.55559/jess.v1i2.586>

© 2025 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

 <https://creativecommons.org/licenses/by/4.0>

Research article

Enhancing Machine Learning Model Security in Private Cloud Environments through Cryptographic Techniques

Ayesha Siddiqui¹, Mohd Naved Ul Haq^{2*}, Mohd Nafees³

¹⁻³Department of Computer Science and Engineering, Glocal University, India



ARTICLE INFO

ABSTRACT

Keywords:

Machine learning, Cloud Computing, Cryptography Algorithms, Classifier

Article History:

Received: 11-08-2025

Revised: 26-11-2025

Accepted: 01-12-2025

Published: 11-12-2025

Cloud-based systems frequently encounter more serious security issues, especially when trying to secure stored information from harm. We present a model that acts as a barrier between users and cloud services, making use of modern techniques in machine learning for enhanced protection. Such a model is able to stop network attacks, identify different types of data and safeguard users' information by applying various encryption algorithms based on its relevance. The Random Forest and Decision Tree methods are very accurate at identifying attacks with a score of over 98% and Logistic Regression also reaches or surpasses 98%. Important classified data in the cloud is secured using methods such as Twofish, Blowfish and the Advanced Encryption Standard (AES).

Introduction

Machine learning, in particular, has transformed computing as more secure private clouds have emerged. Organizations are increasingly relying on private cloud solutions to protect sensitive data and maximize the benefits of machine learning. When we combine secure private clouds and machine learning, complex security issues arise, and cryptography becomes extremely important [1].

It is smart to apply cryptographic security to private cloud systems for machine learning to protect the increasing demand for confidentiality and safe storage of data. Big data and machine learning decisions can face serious security and privacy challenges. By using cryptographic techniques, we ensure that private ML data and models are not modified or accessed illegally.

This study explores the ways in which protocols for machine learning are connected and protected in private cloud systems. Through cryptographic security, this cooperation not only ensures machine learning continues to be a secret process but also gives stakeholders confidence in sharing important data in private clouds. We then look at the importance of protecting cryptographic security in secure private clouds and explain how vital it is to ensure machine learning projects can be done securely.

Private cloud helps businesses by allowing them to deploy their resources either over the internet to the public or privately within their internal systems. Many people prefer private cloud services offered by providers or organizations due to the greater benefits these offer. Its main features are self-service, the ability to scale, adaptability to different types of data and strong administration and control. The use of firewall services and internal hosting in the private cloud guarantees more security by letting only approved users have access to the data and preventing unauthorized use [2]. In recent research, a new way of classifying threats has been introduced [3]. The system uses machine learning algorithms, carried out using both supervised and unsupervised learning, to understand security challenges. You start by selecting the important model characteristics and group threats according

to their differences, including those that affect all networks as well as those that are unique to the cloud environment.

Literature Review

Ze Cheng He et al. [4] outlines a DDoS attack detection system that relies on machine learning to protect cloud networks from attacks by anonymous virtual machines. By using statistics collected on the cloud server's hypervisor and virtual machines, the system manages to detect all DDoS traffic with an accuracy over 99.7%, making sure that the false positive rate stays low at 0.07% or even lower. Early on, the system blocks the outbound network packets, acting as the first intervention and keeping the cloud provider's reputation intact. Further developing the system with multiple machine learning methods, mainly aimed at strengthening unsupervised machine learning and increasing the tool's capabilities to detect several different DDoS attack attempts.

Ghassan et al. [5] states that the use of cloud computing may have information privacy risks and offers a solution using RSA encryption and CHAP authentication. Using this method, both confidentiality and access control are ensured, making the method practical and successful. This approach deals with cloud security issues by using RSA encryption and an authentication protocol which prevents everyone but authorized users from accessing the information.

Mahmoud M. Sakr and his colleagues [6] present a solution to security problems in cloud computing by designing a NIDS that detects unusual activity. The system makes use of the SVM classifier and couples Binary-based Particle Swarm Optimization (BPSO) and Standard-based Particle Swarm Optimization (SPSO) for both choosing the correct features and setting optimal parameters. The NIDS is evaluated with the NSL-KDD dataset and is proven to highly accurately detect several types of attacks with very low false positives. In comparisons, Nipper is found to be more effective than other Intrusion Detection Systems (IDSs). It focuses on ways to set the parameters of the classification algorithm and use the best features for the network design.

*** Corresponding Author:**

✉ navedmuzakkir@gmail.com (M. N. U. Haq)

doi: <https://doi.org/10.55559/jess.v1i2.587>

© 2024 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

 <https://creativecommons.org/licenses/by/4.0>

Gopal Krishna Shyam et.al [7] Summary: The paper looks at the problems related to security, focusing on data privacy, authentication and network security in cloud computing. While cloud technology helps businesses lower costs and be more convenient, it is not without risks such as data breaches and distributed attacks. The writer suggests using tools such as next-generation firewalls and control-based technologies to deal with such issues. The study covers both traditional and advanced artificial intelligence approaches and lists areas in artificial intelligence that still need to be explored. The paper points out the usefulness of such strategies and shows how machine learning is becoming more valuable in safeguarding the cloud.

In the research by Ibrahim S. I. Abuhaiba et.al [8], the objective was to enhance Arabic text document classification using four models with distinct algorithms. Initially, I applied rules that didn't vary, with majority voting between seven classifiers. This resulted in an accuracy of 95.3% after 836 seconds. The second model worked with stacking, resulting in very high accuracies of 99.2% for Naïve Bayes and 99.4% for linear regression, although it required more time to train. The third model adopted AdaBoost together with C4.5, resulting in a higher accuracy of 95.3% with 5 iterations and 99.5% with 10 iterations. The fourth model used the bagging algorithm with a Decision Tree, reaching an accuracy of 93.7% (based on 5 iterations).

99.4% (10 iterations). They performed better even though there were some issues with the models.

various classifiers are measured by their accuracy, precision, recall and F-measure scores. Moreover, incorporating alternative classifiers made stacked models faster to train and easier to use with larger data sets.

Xin Li et.al propose the LNNLS-KH algorithm which fixes the "dimensional disaster" problem in network intrusion detection by selecting features with high accuracy [9]. The algorithm uses linear nearest neighbour lasso optimization and creates a fitness function that counts the number of chosen features and the accuracy of the classification. Results from testing on NSL-KDD and CICIDS2017 suggest that the method is effective, as it reduces the number of features by 44% to 57.85% and performs more accurately than similar algorithms. LNNLS-KH's potential to avoid staying stuck in local optima is emphasized and the researchers suggest working on data balancing techniques and hybrid combinations for better performance in feature selection.

In their study, N. Pandeewari et al. [10] introduced the Hypervisor Detector which identifies anomalies at the hypervisor layer in cloud systems. The system performs well in spotting both kinds of threats, using a combination of FCM-ANN and hybrid Fuzzy C-Means clustering

outsider attacks. The Hypervisor Detector, when tested on the DARPA KDD dataset with Naïve Bayes and Classic ANN, displays a high amount of accuracy and few false reports, most of all in detecting infrequent cyber-attacks. Including fuzzy clustering, training deep ANN sections with the results and a Fuzzy aggregation module in the FCM-ANN model, boosts the learning ability of the ANN. This demonstrates that it is highly effective at spotting unauthorized access to cloud networks.

Basel Saleh Al-Attab et al. [11] Given the rising security problems with cloud computing, the paper presents a new way to secure data by using hybrid encryption to tackle key vulnerabilities, fast processing and speed. The algorithm is designed to stress data security by putting emphasis on cryptography and it uses asymmetric key, secret sharing and key exchange. By using both approaches, the goal is to make data more secure in the cloud. Increasing the use of security algorithms in managing and handling data systems. Developing the algorithm

to specifically satisfy cloud computing requirements, putting priority on quick and efficient handling of data

This research [12] strongly suggests that having strong access controls and including MFA is necessary for protecting data saved in the cloud. The study points out that traditional MFA systems are overly inconvenient and that cloud servers can be insecure which is why a new trust model is created to change the authentication procedure according to the device in use. Using biometrics on public devices and one-factor authentication for private devices, the trust-based MFA gets better results. With the introduction of the MACA system, both multifactor authenticity and privacy are protected, since it combines a password and a hybrid user profile, making the whole process more efficient and resourceful as indicated by the evaluation results.

In [13], Deukjo Hong et.al put forth the LEA block cipher which is suitable for software encryption and comes with 128-bit block sizes as well as key sizes of 128, 192 or 256 bits. Results show that experiments outperform AES on several platforms and LEA is able to maintain a reduced code size. Its software works well in practice with effective throughput and strong defense against various cipher attacks. While the research has performed very well, the authors suggest that there are further improvements that could be made.

This research by Dursun Delen et.al [14] discusses how text mining is important for understanding large volumes of unstructured data. Using text mining on abstracts from important Management Information Systems journals lets us analyze trends and group together similar research topics. Automated ways of managing data are becoming more valuable because of the large amount of information being processed. It is expected that future efforts will develop algorithms that can handle synonyms and the context of words. It is suggested to use both data mining and text mining for a complete way to extract knowledge from any type of information.

The study conducted by Hasan Kamel et.al [15] looks at SDN security risks and proposes using machine learning to identify and classify DDoS attacks in such networks. When I used Dataset with UDP, TCP and ICMP protocols, my proposed Evolutionary Decision Tree (EDT) model, optimized with the Genetic Algorithm (GA), achieved an impressive classification accuracy of 99.46%. Thanks to selecting the right hyperparameters, the GA-enhanced model achieved strong performance in separating normal and attack traffic.

Singh et.al [16] This work proposes a way to make sure that data is securely exchanged between federated cloud entities by performing mutual authentication. Using Elliptic Curve Cryptography and Schnorr's signature scheme, the method ensures secure exchange of messages. It also includes a real-time threat detection system using an ensemble Voting Classifier based on machine learning. With the help of Canadian Institute for Cybersecurity Datasets and ProVerif tool, the protocol is proven to be efficient in terms of security and the cost of communication. Thanks to its resilience against attacks, the lightweight protocol provides anonymity to users and protects session keys, so it is safe to use for online data exchange in a multi-cloud setting.

In their study, Abbas Jasem Altamemi et.al [17] use machine learning to quickly spot DDoS attacks in Software Defined Networking (SDN). The algorithms examined in the study are Decision Tree (DT), Naïve Bayes (NB) and Logistic Regression (LR) which are used for classifying DDoS attacks in SDN. The

the proposed system outperforms others in accuracy, reaching 99.90% for DT. By using machine learning, SDN is able to respond swiftly to DDoS attacks. Finding ways to make the system more optimized, faster in responding and able to grow larger without costing too much.

Hassan and team [18] This paper presents an approach for detecting and mitigating DDoS attacks in IoT networks using Fog Computing. Being close to IoT devices, Fog Computing can detect attacks quickly and accurately. It uses the method of traffic randomness measurements along with the KNN approach in machine learning. The accuracy of the system is very high when it comes to detecting faces. The study reported success in TCP attacks at 100%, 98.79% for UDP attacks and 100% for ICMP attacks. It enables fast action against an assault, lessening the burden on the hardware. Introduce different types of DDoS attacks and update physical detection capabilities for Fog Computing.

Proposed Work

The proposed model includes adding a third-party layer between users and the private cloud, as illustrated in Figure 1. Using ML, the model determines if a user's request is normal or appears to indicate a malicious attack. Later, normal requests continue moving forward and harmful ones are quickly detected and stopped. The system is configured using the BBC News dataset, a popular and effective resource for this type of work. Here, requests generated by users are studied and their data on the cloud is arranged according to how important it is—high confidentiality, confidentiality or just basic. After final classification, data is encrypted with suitable algorithms.

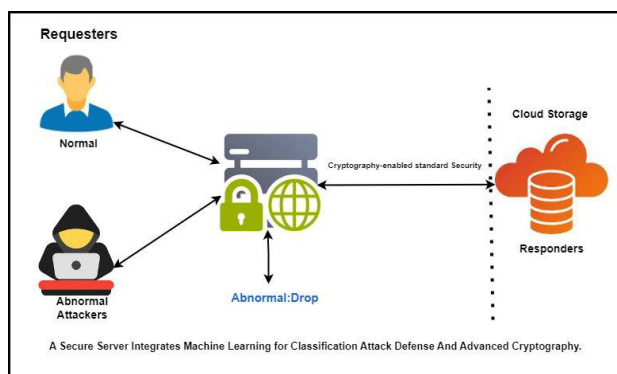


Figure-1: Third-Party Model Situated Between Users and The Private Cloud

The security system includes powerful algorithms such as AES-256, Blowfish and Twofish. To handle datasets with varying privacy levels, the team decided to use BBC News as their source. This data is used to train the classifier which deals with different topics such as Health, Science, Environment, Fashion and technology. The approach suggested for unclassified requests in Figure 2 relies on using request classification data along with machine learning tools.

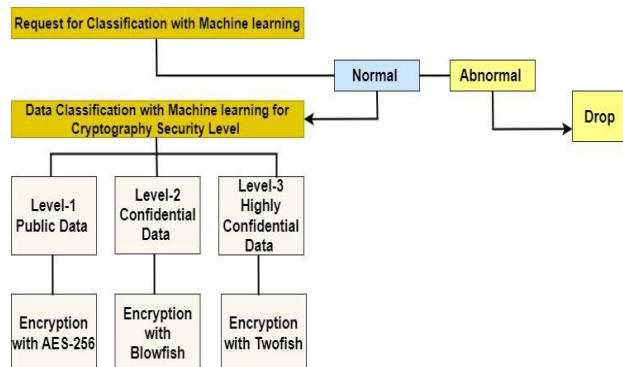


Figure-2: Data Classification Through Machine Learning Techniques

• Using machine learning to organize data into different classes or categories

The system management of text data from the BBC News dataset consists of four major sub-steps: i) Obtaining the data from BBC, ii) preparing the data, iii) selecting important features and iv) training the model to perform classification. BBC news data we are using comes from the British Broadcasting Corporation (BBC) and consists of raw text files available here: <https://www.kaggle.com/search?q=bbc+news>. The files downloaded from the BBC news website document events happening around the country during the chosen time span. 2005 to 2006. The dataset is divided into five folders, called Health, Science, Environment, Fashion and Technology, each filled with news articles connected to that class label.

• Pre-processing

Using tokenization and drop of stop words improves the quality of input data substantially. It is important for this step because it shapes and prepares the text for the next process. According to the BBC dataset, the documents for each article are stored in separate folders, with the category shown in the folder name (e.g., 'technology' for topics on business). Then, every category is identified by a specific number (0 for Health, 1 for Science, 2 for Environment, 3 for Fashion, and 4 for Technology). In Table 1, we can see how the samples are divided among the different categories.

Category	ID Number	Number of Items	Cryptography Algorithm
Health	0	450	Twofish
Science	1	320	Blowfish
Environment	2	390	Twofish
Fashion	3	480	Nothing
Technology	4	350	AES

Table 1. Proposed categories dataset

The classification phase is detailed in Figure 4 with data pre-processing, feature extraction, and the classifier's training-testing steps. The primary reasons for pre-processing datasets are: 1) to make the dataset more manageable for data analysis, and 2) to increase the method's ability to analyze the dataset. It mainly helps by shrinking the size of a dataset by ignoring unnecessary features for categorization.

$$\text{Weight}(x, y) = \frac{tf(x, y)}{\max tf(y)} \times \log\left(\frac{c}{zx} + 1\right)$$

Its address is:

The term x appears in the document y times and is measured by $tf(x, y)$.

The most frequent term in document y is displayed by $\max_tf(y)$. c is the number denoting all documents in the collection.

iv. zx means the number of documents having the term x .

The weight value is found by making $tf(x, y)$ proportional to $\max_tf(y)$ for the given document. The more often the term x appears in the documents, the greater the power of the logarithmic function.

Algorithm Steps

Input

i. The term frequency of term x in document y is denoted as $tf(x, y)$.

ii. The maximum term frequency in document y is expressed by $\max_tf(y)$. iii. The count of documents in the text collection is identified as c .

iv. The count of documents where term x occurs is labeled as zx .

Calculate Weight:

- i. Calculate the normalized term frequency: $tf(x, y)$.
- ii. Apply the logarithmic transformation: $\log(c/zx+1)$.
- iii. Multiply the two results to obtain the term weight.

Output:

The computed term weight for term x in document y .

As previously stated, classification features are implemented in two phases:

- a. In this stage, each request is examined and checked to tell if it is standard or not.
- b. During this phase, we organize and sort all concealed stories by their category.

Skills for data pre-processing are:

a. A lexical analyzer first divides the text into smaller units such as words, letters or entire sentences.

b. A way to process data that uses NLP techniques and stops filtering unnecessary words is known as Stop Word Filtering.

technology. The purpose is to get rid of unnecessary and meaningless terms to slim down the data set using stop words. This simplifies how remaining keywords are found using automated approaches.

d. Scaling: In this part, each word is put in the correct scale (e.g., letters to lowercase) and list is sorted. This predictability brings a uniform format and makes it possible to avoid using capital letters or numbers.

d. Stemming is applied to improve the search process, and Snowball stemming is the method used. It removes the endings or beginning letters from words to get their basic form.

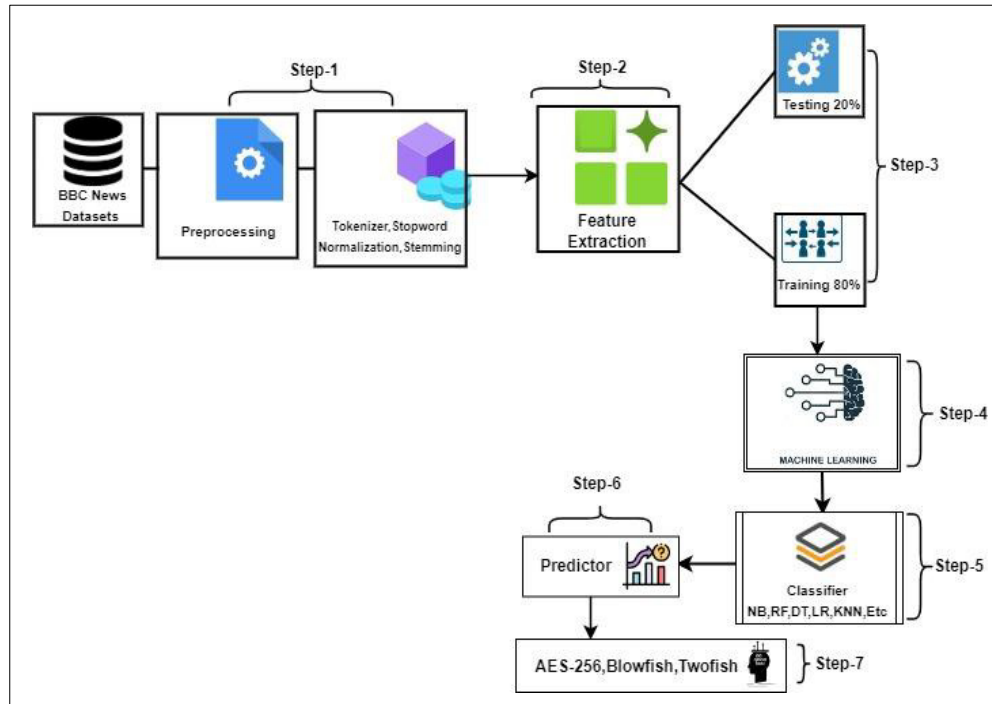


Figure-4 Proposed Model

Methodology

Machine learning (ML) methods are used in this methodology, which consists of two main phases. First, it consists of identifying the requests meant for the private cloud. It identifies which transactions are normal and which may be suspicious. Training for the classifier uses the “BBC News” dataset. In step two, the data in the personal cloud is organized with higher importance, such as Top Secret, being labeled as most sensitive; Confidential is next in importance; and the remaining data is labeled as Basic Data. AES-256, Blowfish, and Twofish are used to encrypt the data categories before they are sent to a server. Read on to learn about the traits, functions, and purposes of machine learning algorithms.

The fact that Naive Bayes is a probabilistic algorithm makes it effective for tasks like text classification and spam filtering. The performance of NB is impressive, since it can make predictions with only moderate understanding of the input. The reason it is popular is that it can deal well with missing values and is efficient. NB is safer from overfitting because it makes simple assumptions and uses probabilities.

RF is known for being effective and reliable because it is an ensemble learning algorithm. RF works well with data because it uses multiple decision trees to deal with non-linear patterns. The ensemble nature of the model tends to reduce the risk of overfitting, though it does require proper tuning. RF is good for solving many classification and regression tasks and is relatively quick to scale.

A feature of DT is its tree structure, known for being easy to interpret and suited to making decisions. In handling non-linearity, DT takes input features and decides whether they belong to one class or the other. But, since overfitting is a risk, the depth and yardstick for splitting need to be set carefully. In cases where interpretability matters a lot, such as binary classification and issues with decision trees, DT is a powerful tool [24].

Logistic Regression, despite the name, is primarily used to perform binary classification and is a linear model. Estimates of probabilities by LR make use of the logistic function for its interpretable results. Thanks to LR's versatility, it is not limited to using it just for binary classification, and can help comprehend how each feature impacts the outcome [25].

Tabel-2 Compression Tables of ML Algorithms

Aspect	NB [2]	RF [3]	DT [4]	LR [5]	KNN [6]
Type	Probabilistic	Ensemble	Decision Tree	Linear Model	Instance-based
Interpretability	Moderate	Moderate to Low	High	Low	Low
Training Speed	Fast (no iterative training)	Moderate to Fast	Fast	Fast	No training phase
Predictive Speed	Fast	Fast	Fast	Fast	Slow (distance alculatation for all points)
Scalability	High	Moderate to Fast	Moderate to High	High	Low to Moderate
Feature Scaling	Not sensitive	Not required	Not required	Required	Sensitive (distance-based)
Handling Missing Values	Handles missing values naturally	Handles missing values naturally	Handles missing values naturally	Requires imputation or elimination	Requires imputation or elimination
Non-linearity	Not applicable (Assumes Independence)	Handles non-linearity well	Handles non-linearity well	Limited	Can capture non-linear Patterns
Robust to Outliers	Not sensitive	Robust	Sensitive	Sensitive	Sensitive
Hyperparameter Tuning	Laplace smoothing (for NB)	Number of trees, depth, features	Depth, splitting criteria	Regularization, possibly feature scaling	Number of neighbours, distance metric
Overfitting	Less prone	Less prone (due to ensemble)	Prone without proper tuning	Less prone	Prone without proper tuning
Use Cases	Text classification, spam filtering	General- purpose classification, regression	Classification, regression	Binary classification, linear problems	Classification, regression, clustering

KNN

KNN classifies data points using the majority class of similar points close to them. Even though KNN gives simple and useful results, its predictive speed is slower, which is noticeable in fast processing situations. KNN is commonly applied in classification, regression, and clustering tasks, as it balances accuracy with understanding [23].

Advanced Encryption Standard

The AES, or Advanced Encryption Standard, is a symmetric key encryption that is commonly applied in different fields. The key sizes offered are 128, 192, and 256 bits, ensuring the highest level of privacy. AES offers high protection with its 10, 12, or 14 round processes. This innovation employs the substitution method.

There is an SPN structure, key expansion, the addition of S-boxes, and key whitening. When introduced in 2001, AES became the preferred choice for encrypting data quickly and completely.

Twofish

Twofish, another symmetric key algorithm, is created for everyday use and experts recommend it.

particularly for constrained environments. The mode works with key lengths of 128, 192, and 256 bits and employs Feistel structure, key expansion, S-boxes, and key whitening. Twofish was developed in 1998 and excels at offering a secure and fast option for different uses.

Blowfish

Blowfish was released in 1993 and ensures strong security for most applications, with special advantages when used in software. To operate, Blowfish adopts a 64-bit fixed key size, Feistel structure, key expansion, and S-boxes, while also including key whitening. It provides medium to high-security strength when locked with 16 rounds. Even though it is not the quickest, Blowfish is appropriate when balancing security and the need for efficiency [26].

Table-3 Cryptographic Algorithms Compression Tables

Factor	AES	Twofish	Blowfish
Algorithm Type	Symmetric	Symmetric	Symmetric
Key Size (bits)	128,192,256	128,192,256	64
Rounds	10,12,14	16	16
Feistel Structure	No	No	Yes
Key Expansion	Yes	Yes	Yes
S-Boxes or Substitution Permutation Networks (SPNs)	Yes	Yes	Yes
Key Whitening	Yes	Yes	Yes
Security Strength	High	Very High	Medium to High
Speed	Fast	Moderate to Fast	Moderate
Confidentiality	Excellent	Excellent	Good
Use Cases	General Purpose, widely adopted	General Purpose, recommended for constrained environments	General Purpose, particularly for software implementations
Year Introduced	2001	1998	1993

Result

In the proposed strategy, the focus is on configuring the server as an intermediary, the major objective of which is to strengthen the security measures between these organizations. Through the utilization of machine learning and encryption techniques, a system has been designed to enhance cloud security and identify potential threats. The "BBC News" dataset is employed for the purpose of classification, training the classifier with privately stored data within a cloud. The evaluation phase includes testing various algorithms such as Naive Bayes, Logistic Regression, K-Nearest Neighbours, Random Forest, and Decision Trees. In the suggested machine learning algorithm-based classification process, two primary phases exist: data training and testing. Based on specific criteria, comparative analysis is conducted using performance metrics like accuracy, precision, recall, and F1- score [9].

Tabel-4 Performance Parameters with Equation

Performance Parameter	Equation
Accuracy	$\frac{\text{True Positives} + \text{True Negatives}}{\text{True Positives} + \text{Fake Positives} + \text{Fake Negatives} + \text{True Negatives}}$
Precision	$\frac{\text{True Positives}}{\text{True Positives} + \text{Fake Positives}}$
Recall	$\frac{\text{True Positives}}{\text{True Positives} + \text{Fake Positives}}$
F1-Score	$\frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$
DR	$\frac{\text{True Positives}}{\text{True Positives} + \text{Fake Negatives}}$
FAR	$\frac{\text{Fake Positives}}{\text{Fake Positives} + \text{True Negatives}}$
ERR	$\frac{b + c}{a+b+c+d}$

- i. TP means that the model correctly identified something positive.
- ii. A false positive (FP) is a case where the model thinks something is positive when it should be considered negative.
- iii. When false negatives occur, the model says something is negative even though it should be positive.
- iv. TN stands for false negatives, which are correctly predicted as negative by the model [19, 20].

To find accuracy, the model is measured by counting its number of correct positives and negatives. It provides an idea of how accurately the system differentiates instances [21].

The main idea behind precision is that it shows how accurate the predictions of positive results are among all positive results identified. It is used to measure how well the model is at picking out positives. [10].

Recall is used to assess how correctly a model can find all cases that belong to a specific class. It assesses the number of actual positives the model correctly detects [11].

F1-Score is a harmonic mean of precision and recall; it helps identify how well a result considers both errors at the same time. In situations where one class is much larger than the other, this proves especially helpful [12].

The False Alarm Rate (FAR) shows how often a detector gives a wrong alert versus the number of real negatives. This brings forward the tendency of the model to incorrectly label negative instances as positive [16].

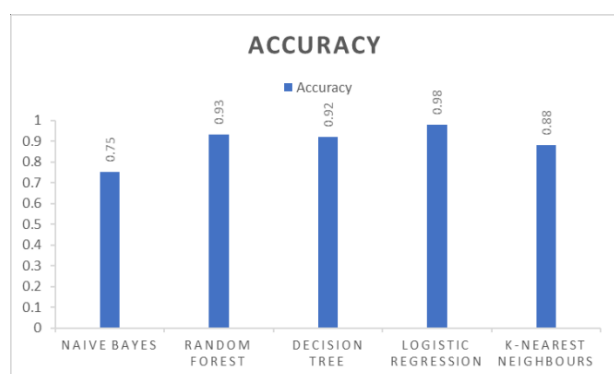
Error Rate (ERR) presents a comprehensive evaluation of classification errors, considering both false positives and false negatives relative to the total number of instances. It serves as a complement to accuracy [18].

Table 2 and Figure 5 provide an outcome of the algorithms that were used. When compared to other algorithms, the DT and RF algorithms perform better in terms of accuracy and detection rate, building algorithm, as well as other areas; but, since the LR method relies on randomization, it is thought to be the fastest. This study suggests LR's optimal efficiency for examined datasets may be attributed to its quick training model and straightforward implementation.

Table -5 Result Table of Algorithms

Aspect	Naive Bayes	Random Forest	Decision Tree	Logistic Regression	KNNK- Nearest Neighbours
Precision	0.79	0.96	0.94	0.88	0.91
Accuracy	0.75	0.93	0.92	0.98	0.88
Recall	0.78	0.95	0.93	0.87	0.90
F1-Score	0.78	0.96	0.94	0.89	0.92
FAR	0.41	0.03	0.05	0.11	0.13
DR (Detection Rate)	0.92	0.97	0.98	0.86	0.93

In short, Logistic Regression simplifies running time by converting the features of the dataset into groups of related attributes. It then ranks the clusters based on the similarities among them. LR needs time to consider all the data at once, but it quickly finds accurate results. The visual representation of the results from the proposed phase is shown in Figure 5.

**Figure 5 Accuracy Graph for all Algorithms**

Conclusion

The paper presents a secure cloud architecture that makes use of machine learning and cryptography. It uses several levels of encryption, protecting sensitive data first while keeping the use of resources at a minimum for regular data. Using the BBC classification dataset, it was observed that the LR algorithm among several other ML models was the most effective in identifying attack traffic from normal network traffic. In the second phase, the LR model accurately classifies different data types with a high precision of 98%.

References

- [1] Jabbar, A. A., & Bhaya, W. S. (2023). Security of private cloud using machine learning and cryptography. *Bulletin of Electrical Engineering and Informatics*, 12(1), 561-569.
- [2] Goyal, S. (2014). Public vs private vs hybrid vs community-cloud computing: a critical review. *International Journal of Computer Networks & Information Security*, 6, 20.
- [3] Masetic, Z., Hajdarevic, K., & Dogru, N. (2017). Cloud computing threats classification model based on the detection feasibility of machine learning algorithms. 2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 1314-1318. doi: 10.23919/MIPRO.2017.7973626.
- [4] He, Z., Zhang, T., & Lee, R. B. (2017). Machine Learning Based DDoS Attack Detection from Source Side in Cloud. *Proceedings of the 4th IEEE International Conference on Cyber Security and Cloud Computing (CSCloud 2017)*, 114-120. doi: 10.1109/CSCloud.2017.58.
- [5] Mahmood, A. L. G. S. (2017). Data Security Protection in Cloud Computing by using Encryption. *Kirkuk University Journal/Scientific Studies*, 12(4), 849-1992.
- [6] Sakr, M. M., Tawfeeq, M. A., & El-Sisi, A. B. (2019). Network Intrusion Detection System based PSO- SVM for Cloud Computing. *International Journal of Computer Networks & Information Security*, 11(3), 22-29. doi: 10.5815/ijcnis.2019.03.04.
- [7] Shyam, G. K., & Doddi, S. (2019). Achieving Cloud Security Solutions through Machine and Non- Machine Learning Techniques: A Survey. *Journal of Engineering Science and Technology Review*, 12(3).
- [8] Abuhaiba, I. S. I., & Dawoud, H. M. (2017). Combining different approaches to improve Arabic text documents classification. *International Journal of Intelligent Systems and Applications*, 9(4), 39. doi: 10.5815/ijisa.2017.04.05.
- [9] Li, X., Yi, P., Wei, W., Jiang, Y., & Tian, L. (2021). LNNLS-KH: A Feature Selection Method for Network Intrusion Detection. *Security and Communication Networks*, 2021, 8830431. doi: 10.1155/2021/8830431.
- [10] Pandeeswari, N., & Kumar, G. (2016). Anomaly detection system in cloud environment using fuzzy clustering-based ANN. *Mobile Networks and Applications*, 21(3), 494-505. doi: 10.1007/s11036-015-0644-x.
- [11] Al-Attab, B. S., & Fadewar, H. S. (2018). Hybrid data encryption technique for data security in cloud computing. *Sinhgad Institute of Management and Computer Applications*, 221-224.
- [12] Anakath, A. S., Rajakumar, S., & Ambika, S. (2019). Privacy preserving multi-factor authentication using trust management. *Cluster Computing*, 22(5), 10817-10823. doi: 10.1007/s10586-017-1181-0.
- [13] Hong, D., Lee, J.-K., Kim, D.-C., Kwon, D., Ryu, K. H., & Lee, D.-G. (2013). LEA: A 128-bit block cipher for fast encryption on common processors. *International Workshop on Information Security Applications*, 3-27. doi: 10.1007/978-3-319-05149-9_1.
- [14] Delen, D., & Crossland, M. D. (2008). Seeding the survey and analysis of research literature with text mining. *Expert Systems with Applications*, 34(3), 1707-1720. doi: 10.1016/j.eswa.2007.01.035.
- [15] Kamel, H., & Abdullah, M. Z. (2022). Distributed denial of service attacks detection for software- defined networks based on evolutionary decision tree model. *Bulletin of Electrical Engineering and Informatics*, 11(4), 2322-2330. doi: 10.11591/eei.v11i4.3835.
- [16] Singh, A. K., & Saxena, D. (2022). A cryptography and machine learning-based authentication for secure data-sharing in a federated cloud services environment. *Journal of Applied Security Research*, 17(3), 385-412.
- [17] Altamemi, A. J., Abdulhassan, A., & Obeis, N. T. (2022). DDoS attack detection in software-defined networking controller using

- machine learning techniques. *Bulletin of Electrical Engineering and Informatics*, 11(5), 2836–2844. doi: 10.11591/eei.v11i5.4155.
- [18] Hassan, K. F., & Manaa, M. E. (2022). Detection and mitigation of DDoS attacks in the Internet of Things using a fog computing hybrid approach. *Bulletin of Electrical Engineering and Informatics*, 11(3), 1604–1613. doi: 10.11591/eei.v11i3.3643.
- [19] Kumar, V., Sinha, D., Das, A. K., Pandey, S. C., & Goswami, R. T. (2020). An integrated rule-based intrusion detection system: analysis on UNSW-NB15 data set and the real-time online dataset. *Cluster Computing*, 23(2), 1397–1418. doi: 10.1007/s10586-019-03008-x.
- [20] Vora, U., Mahato, J., Dasgupta, H., Kumar, A., & Ghosh, S. K. (2021). Machine Learning–Based Security in Cloud Database—A Survey. *Machine Learning Techniques and Analysis for Cloud Security*, 239–269. doi: 10.1002/9781119764113.ch12.
- [21] Uçtu, G., Alkan, M., Doğru, İ. A., & Dörterler, M. (2021). A suggested testbed to evaluate multicast network and threat prevention performance of Next Generation Firewalls. *Future Generation Computer Systems*, 124, 56–67. doi: 10.1016/j.future.2021.05.013.
- [22] Bhavani, D. D., Vasavi, A., & Keshava P. T. (2016). Machine Learning: A Critical Review of Classification Techniques. *International Journal of Advanced Research in Computer and Communication Engineering*, 5(3), 22-28.
- [23] Narudin, F. A., et al. (2016). Evaluation of machine learning classifiers for mobile malware detection. *Soft Computing*, 20, 343-357.
- [24] Costa, V. G., & Pedreira, C. E. (2023). Recent advances in decision trees: An updated survey. *Artificial Intelligence Review*, 56(5), 4765–4800.
- [25] Belavagi, M. C., & Muniyal, B. (2016). Performance evaluation of supervised machine learning algorithms for intrusion detection. *Procedia Computer Science*, 89, 117–123.
- [26] Ul Haq, M. N., & Kumar, N. (2021). A novel data classification-based scheme for cloud data security using various cryptographic algorithms. *International Review of Applied Sciences and Engineering*.



Review Article

Insights into E-waste as Global Concern: Sources, Composition and Impacts

Mohd Yusuf^{1*}, Shafat Ahmad Khan², Sandeep Kumar Chaurasiya¹

¹Glocal University, Mirzapur Pole, Saharanpur, Uttar Pradesh- 247121 India

²SBAS, Galgotias University, Greater Noida, Uttar Pradesh 203201 India



ARTICLE INFO

ABSTRACT

Keywords:

Electronic waste, electrical and electronic equipment (EEE), metal oxide hazard, radioactive pollution, recycling

Article History:

Received: 11-08-2025

Revised: 26-11-2025

Accepted: 01-12-2025

Published: 11-12-2025

Since the 18th century, science and technology have driven industrial growth and improved human life. In the 21st century, rapid technological development has changed not only industries and lifestyles but has also brought new environmental challenges. One of the biggest issues today is the continuously increasing volume of electronic waste originating from discarded electrical and electronic equipment. Inaccurate and improper e-waste disposal and recycling lead to the release of toxic substances, posing a great threat to the environment and human health. This review discusses global e-waste sources, composition, and impacts.

1. Introduction

E-waste, also known as electronic waste, refers to discarded or surplus electronic devices, appliances, and components. Examples include computers, smartphones, televisions, refrigerators, and other household and industrial electronic equipment. E-waste is a rapidly growing global concern due to its potential negative impacts on the environment and human health. The rapid advancement of technology and the constant release of new electronic devices have led to a rapid increase in the amount of e-waste generated [1]. As these devices reach the end of their useful life, they are often discarded, leading to the buildup of e-waste in landfills and other disposal sites. E-waste contains a wide range of toxic materials, including lead, cadmium, mercury, and flame retardants, which can have harmful effects on the environment and human health if not properly managed. Improper disposal of e-waste can lead to the release of these toxins into the air, water, and soil, potentially contaminating food and drinking water. Current management practices for e-waste include recycling, incineration, and landfilling. However, many e-waste recycling operations in developing countries are informal, and lack proper safety and environmental protections, resulting in the release of toxic chemicals and pollutants into the environment [2]. To address the global concern of e-waste, modern perspectives include implementing extended producer responsibility programs, which place the responsibility for e-waste management on the manufacturers of electronic devices; promoting circular economy principles, which aim to reduce waste and resource consumption through product design, reuse, and recycling; and encouraging sustainable design, which aims to reduce the environmental impact of electronic products throughout their lifecycle.

The increased demand for electronics globally has resulted in a significant growth in the amount of e-waste created. This tendency is especially noticeable in emerging nations with a

burgeoning middle class and increased access to technology. According to a World Economic Forum estimate, e-waste is expected to exceed 74 million metric tons by 2030 [3]. Lead, mercury, cadmium, and brominated flame retardants are among the harmful compounds found in e-waste [4]. When not adequately handled, these compounds can pose major environmental and health problems. Lead, for example, can harm the neurological system and create developmental issues in children. Mercury may harm the brain and kidneys, while cadmium can harm the kidneys and cause cancer. E-waste that is improperly disposed of can also contaminate soil and water, posing risks to human health and wildlife [5].

The lack of proper e-waste management is a significant challenge, particularly in developing countries where there may be limited resources and infrastructure for managing electronic waste. Many e-waste items end up in landfills or are illegally exported to other countries, where they may be handled in unsafe ways. This can lead to environmental contamination and health risks for people who live near the waste sites. There have been calls for increased regulation to address the e-waste problem. Many countries have enacted laws and regulations to promote proper e-waste management, including recycling and disposal standards [3, 6-7]. However, enforcement of these regulations can be a challenge, and there is a need for greater international cooperation to address the issue.

There has been growing awareness about the e-waste problem and its impact on the environment and human health. Many companies and organizations are taking steps to address the issue, such as implementing sustainable design practices, improving recycling programs, and reducing the use of hazardous materials in electronics by minimizing e-waste resulted in gaining positive applicability of green chemistry in circular economy [2,8]. Consumers are also becoming more aware of the issue and seeking out ways to responsibly dispose of their electronic devices.

* Corresponding Author:

✉ yusuf1020@gmail.com (M. Yusuf)

doi: <https://doi.org/10.55559/jess.v1i2.587>

© 2024 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

<https://creativecommons.org/licenses/by/4.0>

Moreover, the e-waste concern in 21st century has been driven by the increasing amount of electronic waste generated worldwide, as well as the environmental and health risks associated with improper e-waste management. There is a need for greater regulation and cooperation to address the issue, as well as a growing awareness of the problem among consumers, companies, and organizations [9]. The e-waste is a worldwide issue that affects both industrialized and poor countries. E-waste is shipped from developed countries to poor ones for recycling or disposal. This activity, known as "e-waste dumping," is prohibited by international law, yet it continues to occur owing to a lack of effective laws and enforcement. Developing nations sometimes have fewer environmental and labor laws, making them a more appealing destination for e-waste. Developed countries, such as the United States, Japan, and Germany, create the most e-waste per capita, while emerging countries are increasing their production [9-13]. The review demonstrates the current global e-waste scenarios and the health hazards, which could delay the achievement of sustainable development targets, in terms of their composition sources, composition, and associated impacts, to provide a comprehensive workflow for the requirements of e-

waste awareness building and technological improvement to facilitate global long-term sustainable development.

2. Sources

Electronic garbage, or e-waste, is the term used to describe abandoned electronic devices such as computers, cellphones, televisions, and other electronic equipment [14]. Consumers, corporations, and institutions are all potential contributors of e-waste. Electronic gadgets are frequently discarded by consumers when they become obsolete or no longer perform correctly. Companies and organizations create e-waste when they upgrade their electronic equipment, and these things can soon become obsolete owing to technological advances [15]. Moreover, the production of electronic gadgets creates waste, such as scrap materials, damaged goods, and surplus inventories. Lastly, inappropriate electronic device disposal can add to e-waste since many individuals dispose of these goods in landfills rather than recycling them. The chief sources of e-wastes is schematically given in Fig. 1.

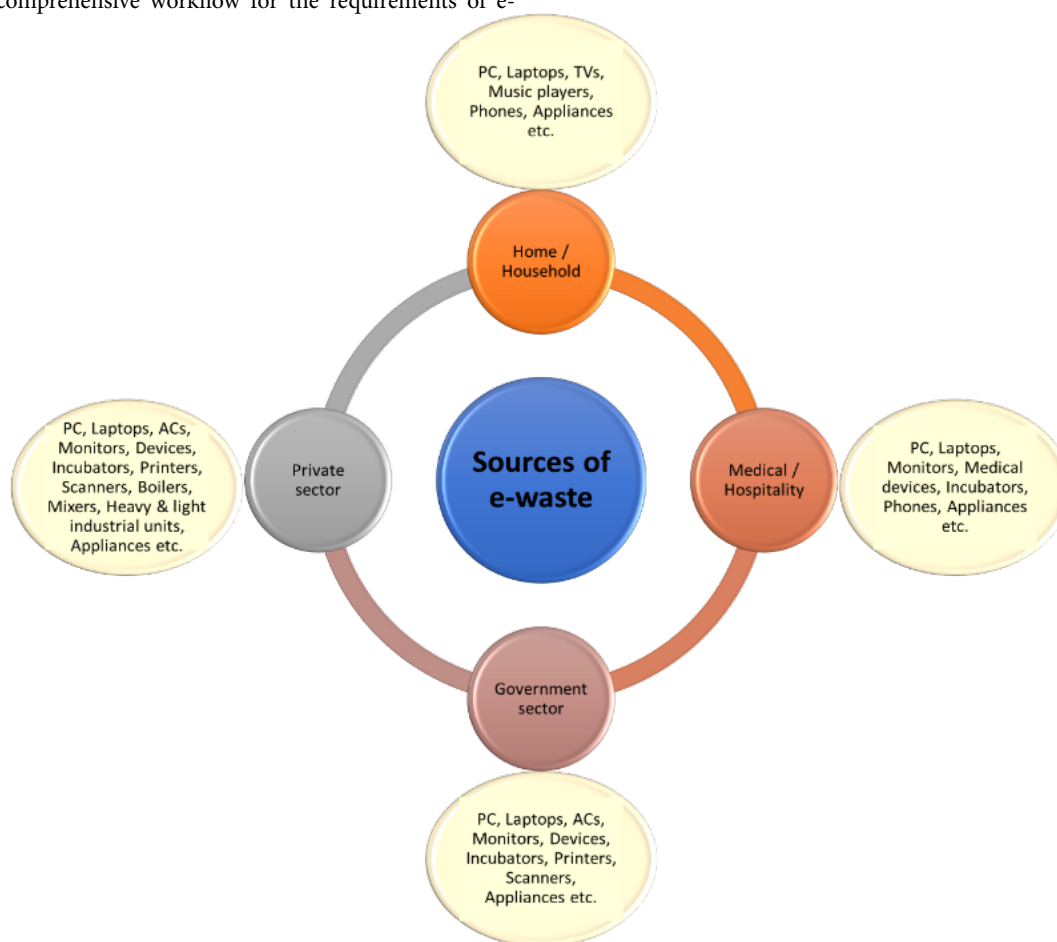


Fig. 1: Schematic representation of the Chief sources of e-waste

Al-Salem et al. in 2021 described a current summary of e-waste creation, recycling procedures, and growing management issues and defined in detail, the conditions of global e-waste management, the issues that different areas confront, and developing technology for e-waste recycling that is most desirable in the current era [16]. In a similar report, Singh and Sharma (2021) summarized further the worldwide e-waste construction and managing techniques [17]. It also goes into the environmental and health consequences of e-waste, as well as the legislation and regulations in place to handle it and it delves into innovative e-

waste management methods, such as recycling and recovery techniques [14,17]. E-waste includes a wide range of sources, described herein:

2.1 Computers and laptops

Computers and laptops are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. When disposing of a computer or laptop, it is

important to remove any personal data or confidential information stored on the device to protect your privacy. This can be done by using secure data erasure software or physically destroying the hard drive. Many computers and laptops also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Like other electronic devices, many computers and laptops can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.2 Televisions

Televisions are considered e-waste when they are no longer functional or have been replaced with newer models. Once televisions are no longer functioning or have been replaced by newer ones, they are classified as e-waste. Televisions include a range of elements, including plastics, metals, and electrical components, all of which may be recycled or disposed of securely to protect the environment and human health. To preserve your privacy, it is vital to erase any personal data or private information saved on a television before disposing of it, but this is not usually an issue with televisions. Many televisions also have batteries, which should be removed and disposed of appropriately because they can be dangerous if not handled properly. The situation worth noting that older televisions, such as cathode ray tube (CRT) televisions, contain a lot of lead. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.3 Cell phones and smartphones

Cell phones and smartphones are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. It is important to remove any personal data or confidential information stored on the device to protect your privacy, when disposing of a cell phone or smartphone. This can be done by using secure data erasure software or restoring the device to factory settings. Many cell phones and smartphones also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Similarly, to the other electronic devices, many cell phones and smartphones can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. Additionally, many companies have trade-in programs that allow consumers to trade their old devices for discounts on new ones, or even donate them to be used in developing countries where access to technology is limited.

2.4 Tablets and e-readers

Also, tablets and e-readers are considered as e-waste because they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

Many tablets and e-readers, like other electronic gadgets, may be recycled through in-store take-back programs or through

specialist e-waste recycling facilities. These facilities will disassemble the items and recycle or dispose of them safely. This not only helps to reduce pollution but also to save resources. Furthermore, many firms have trade-in programs that allow customers to turn in their old gadgets for discounts on new ones, or even donate them to be used in underdeveloped nations where access to technology is limited [18]. After disposing of a tablet or e-reader, it is important to remove any personal data or confidential information stored on the device to protect your privacy. This can be done by using secure data erasure software or restoring the device to factory settings. Many tablets and e-readers also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly.

2.5 DVD players and VCR (Video Cassettes Recorders)

DVD players and VCRs (Video cassette recorders) are considered e-waste when they are no longer functional or have been replaced with newer models. Like other electronic devices, many DVD players and VCRs can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. The devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. The disposing of a DVD player or VCR, it is important to remove any personal data or confidential information stored on the device to protect your privacy, but this is not typically an issue with these devices. Many DVD players and VCRs also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly.

2.6 Gaming consoles

Gaming consoles, such as the Xbox, PlayStation, and Nintendo consoles, are also considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

When disposing of a gaming console, it is important to remove any personal data or confidential information stored on the device to protect your privacy. Many gaming consoles also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Like other electronic devices, many gaming consoles can be recycled through in-store take-back programs or through specialized e-waste recycling facilities [16,19]. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.7 Printers and scanners

Printers and scanners are also considered e-waste when they are no longer functional or have been replaced with newer models. Printers can contain a variety of materials such as plastics, metals, and electronic components. Scanners contain electronic components as well. Many of these materials can be recycled or safely disposed of to prevent harm to the environment and human health. Similar other electronic devices, many printers and scanners can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities

will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. To preserve your privacy, it is critical to erase any personal data or secret information contained on printers and scanners before disposing of them. Many printers and scanners have ink or toner cartridges, which may be recycled or disposed of securely separately.

2.8 Home appliances (microwaves and refrigerators)

Microwaves, refrigerators, washing machines, and dryers are examples of e-waste. These appliances can become e-waste when they are no longer working or have been replaced by newer versions. Because of their size and weight, they are sometimes more difficult to dispose of than smaller electronic goods. Some household appliances may also contain hazardous elements, such as refrigerants, which must be handled and disposed of correctly to avoid harm to the environment and human health. Numerous home appliances can also be recycled, either through in-store take-back programs or through specialized e-waste recycling facilities. The recycling process typically involves breaking down the appliances into their component parts, which can then be used to make new products or safely dispose of any hazardous materials. It also prevents them from ending up in landfills and polluting the environment.

2.9 Home theater systems

Home theater systems, also known as home entertainment systems, include a combination of electronic devices such as a TV, DVD player, speakers, amplifiers and other components like

streaming devices, gaming consoles and others. They are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

2.10 Small electronic devices (calculators and digital cameras)

E-waste includes calculators and digital cameras that are no longer working or have been replaced by newer ones. These devices often contain a range of materials, including plastics, metals, and electrical components, which may be recycled or disposed of securely to protect the environment and human health. These items may be discarded due to obsolescence, broken or malfunctioning parts, or simply because they have been replaced with newer models.

3. Chemical composition

The chemical composition of e-waste varies according to the kind of electronic equipment and its age [20-21], however the following are some of the most frequent compounds found in e-waste: *Metals*: E-waste contains a variety of metals, including copper, aluminum, iron, gold, silver, palladium, and platinum (Fig. 2). These metals are used in electronic products for their electrical conductivity, durability, and resistance to corrosion. E-waste contains a variety of metals that are used in electronic products for their electrical conductivity, durability, and other properties [22-23]. Some of the most common metals found in e-waste include [24]:

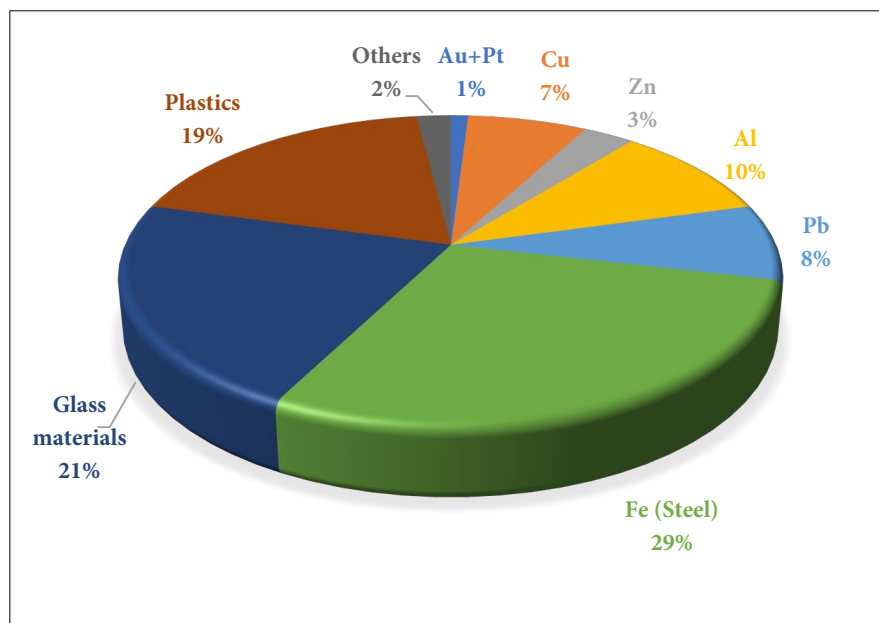


Fig. 2: Schematic illustration of e-waste composition.

- Cu: Copper is used in electronic products for its excellent electrical conductivity. It is commonly found in wiring, printed circuit boards (PCBs), and other components.
- Al: Aluminum is used in electronic products for its light weight and corrosion resistance. It is commonly found in components such as heat sinks and casings.
- Au: Gold is used in electronic products for its excellent electrical conductivity and resistance to corrosion. It is commonly found in connectors and other components.
- Ag: Silver is used in electronic products for its excellent electrical conductivity. It is commonly found in contacts, switches, and other components.
- Pd: Palladium is used in electronic products for its ability to absorb hydrogen. It is commonly found in components such as capacitors and resistors.
- Pt: Platinum is used in electronic products for its excellent electrical conductivity and resistance to corrosion. It is commonly found in contacts and other components.
- Pb: Lead is used in electronic products for its ability to absorb vibrations and to shield against radiation. However, due to its toxicity, lead has been phased out of many electronic products, and the use of lead in new products is restricted by various regulations.

Plastics: Electronic products contain a variety of plastic materials, including polycarbonate, polyethylene, polypropylene, and PVC. These plastics are used for their insulating properties and durability.

Glass materials: Electronic devices, such as CRT monitors and televisions, contain glass components. The glass used in electronic devices is typically a type of leaded glass, which can pose environmental and health risks if not properly disposed off. Cathode Ray Tube glass, for example, is composed of mainly SiO₂, CaO, and Na.

Flame retardant components: Electronic devices often contain flame retardants, which are chemicals added to the materials used in electronic products to reduce their flammability. Common flame retardants used in electronic products include brominated flame retardants (BFRs) and phosphorus-based flame retardants (PBFRs).

Printed circuit boards (PCBs) and others: PCBs are used in electronic products to connect electronic components. They contain a variety of metals and other materials, including copper, gold, silver, tin, and lead.

Impacts: Environment and Human being's health

E-waste, or electronic waste, can have significant environmental impacts if not properly managed. E-waste, or electronic garbage, can have severe and far-reaching environmental consequences. Poor e-waste disposal can result in land and water degradation, air pollution, resource depletion, increased energy usage, and greenhouse gas emissions. Hazardous substances found in e-waste, such as lead, mercury, and cadmium, can be released into the environment and harm human health and the environment [24-26]. Furthermore, the production and disposal of electronic products consume a lot of energy and can contribute to climate change. Proper e-waste management measures, including proper electronic device disposal and

recycling, are required to reduce negative environmental consequences and encourage sustainable resource usage. Some of the environmental impacts associated with e-waste are presented in Fig. 3.

The disposal of electronic gadgets and their components is referred to as electronic trash, or e-waste. Many of these products include hazardous compounds including lead, mercury, cadmium, and brominated flame retardants. These substances can seep into the land and water, posing a serious health danger to humans [27-29]. Lead is an extremely hazardous element that, especially in children, can cause major health problems such as developmental delays, learning challenges, and behavioral issues. Mercury is another hazardous element that may harm the nervous system, causing tremors, memory loss, and mood changes. Cadmium is a hazardous metal that has been associated to thyroid issues and developmental delays, whereas brominated flame retardants have been connected to thyroid problems and developmental delays. Toxic dust inhalation during e-waste deconstruction and disposal can cause respiratory difficulties and other health concerns, including lung cancer. Skin irritation, eye difficulties, and headaches can all result from exposure to electronic trash. Furthermore, poor e-waste disposal can lead to environmental contamination, harming local species and ecosystems. The components of e-waste, on the other hand, can have a substantial influence on human health, creating serious and possibly irreparable health issues. To reduce the health and environmental dangers connected with e-waste, electronic gadgets and their components must be properly disposed of and recycled. Electronic garbage, sometimes known as e-waste, refers to a wide spectrum of electronic gadgets and their components. Table 1 depicts some of the most frequent e-waste components [30-35]. Toxic components in electronic trash include mercury, lead, cadmium, polybrominated flame retardants, barium, and lithium, all of which are hazardous to human health. Toxins' harmful health impacts on humans include damage to the brain, heart, liver, kidneys, and skeletal system (Table 1) [36-43].

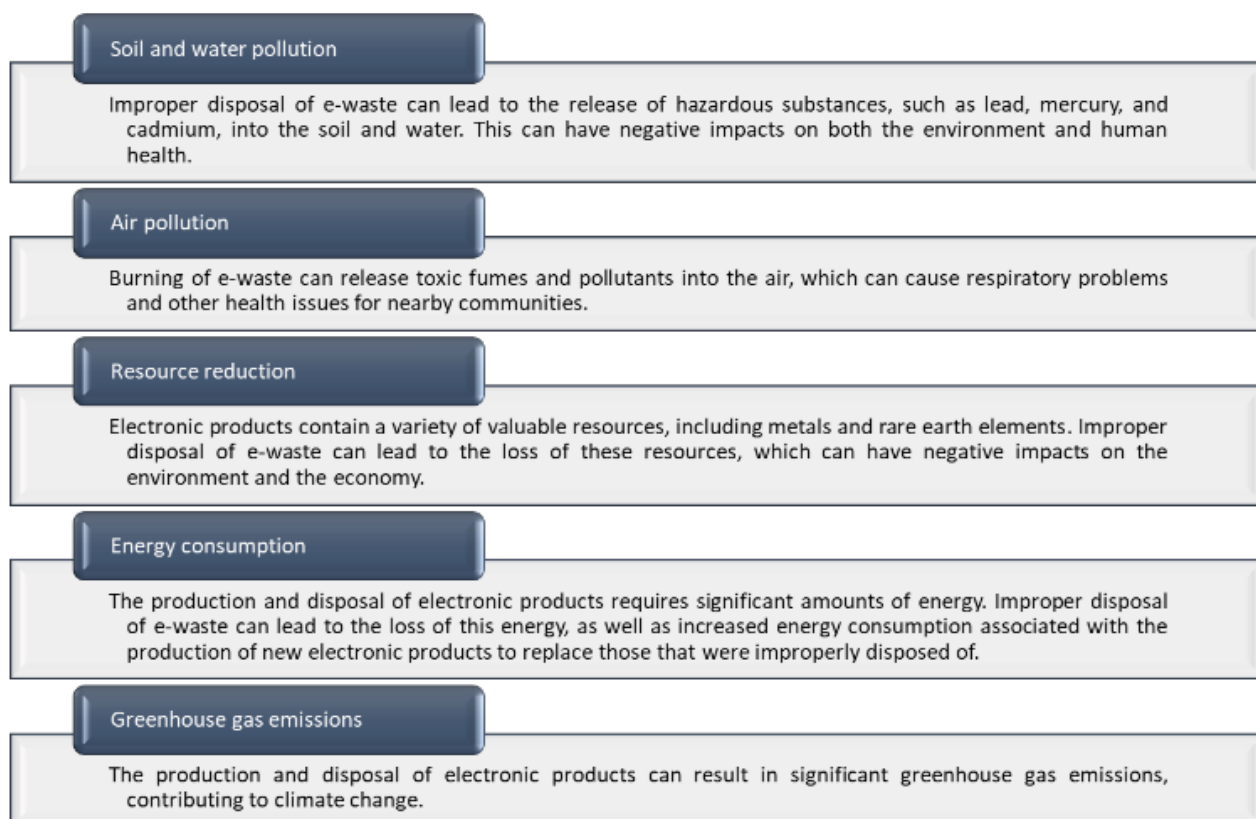


Fig. 3: Illustration of significant environmental impacts of e-waste.

Table 1: Human health impacts of e-waste components [1-4, 8-12, 20-24, 36-43].

Components of e-waste	Chief constituents	Associated health concerns
Cable insulation	PVC (Burning)	Immune system
Plastics housing	Br	Endocrine system
Motherboards	Be	Carcinogenic (Lungs) and Skin disorders (warts) and chronic disease (<i>Berylliosis</i>)
Soldering	Pb	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Behavioral problems
	Sn	
Printed circuit boards (PCBs)	Pb	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Toxic irreversible effects- Teratogenic, neural damage, kidney and liver
	Cd	
Computer monitor/Screens/peripherals	Hg	Chronic damage to brain and skin and Respiratory and skin disorders
Cathode ray tubes	PbO	Kidney, Liver, Heart, Skin Muscle weakness, Damage to liver, heart and spleen Toxic irreversible effects- Teratogenic, neural damage, kidney and liver
	Ba	
	Cd	
Batteries (single-use and rechargeable)	Li	Loss of appetite, seizures, nausea, vomiting, diarrhea
Liquid crystal displays (LCDs)	Volatile organics (VOs)	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage
	Pb	
Hard drives and other data storage devices	Al	Mental disability Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage
	Pb	
Conducting electronic plates (CEP), disposable and rechargeable batteries, luminous substances	Cr	Skin irritation and Lung cancer (<i>Bronchitis</i>) Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Damage to central and peripheral nervous systems and trauma
	Pb	
	Zn	

4. Conclusion and Future Outlook

With fast growth in all categories of electronic products and a relatively short life span, e-waste has become a serious global problem. It contains valuable materials such as gold and copper, as well as harmful substances like lead, mercury, and plastic additives. When e-waste is handled or recycled poorly, it contaminates the air, water, and soil, and creates health risks for humans and animals. To manage e-waste, safe recycling systems, proper legislation, and awareness among the public are greatly needed. All electronic products should be made more repairable, reusable, and recyclable by their very manufacturers. Support from governments toward formal recycling sectors is necessary, along with the encouragement of green technologies in material recovery. In the longer term, the adoption of circular economy concepts where electronics materials is reused rather than discarded will minimize pollution and preserve natural resources. With international cooperation, better technology, and responsible behavior from both producers and consumers in a market economy, e-waste can be transformed from a problem into a valuable resource for sustainable development.

Acknowledgements

The authors are thankful to Glocal University, Saharanpur, Uttar Pradesh, India, for providing technical support and facilities to carry out this work.

Author contribution

Mohd Yusuf: Concept, data collection, visual interpretation, editing manuscript and submission.

Shafat A. Khan: Data interpretation, revising writing, drafting manuscript.

Sandeep K. Chaurasiya: Data interpretation, visual editing, drafting manuscript.

Consent for publication: Not applicable.

Funding Source: No funding was received for this project.

Ethics approval and consent to participate: Not applicable.

Conflict of Interest: The authors declare no competing interests.

References

- [1] Ádám, B., Göen, T., Scheepers, P.T., Adliene, D., Batinic, B., Budnik, L.T., Duca, R.C., Ghosh, M., Giurgiu, D.I., Godderis, L. and Goksel, O., 2021. From inequitable to sustainable e-waste processing for reduction of impact on human health and the environment. *Environmental Research*, 194, p.110728.
- [2] United Nations University (2019). Global E-waste Monitor 2019. <https://www.itu.int/en/ITU-D/Environment/Documents/Global-E-waste%20Monitor%202019.pdf>
- [3] World Economic Forum (2020). The Global E-waste Monitor 2020. https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf
- [4] Environmental Protection Agency (2020). Electronics Donation and Recycling. <https://www.epa.gov/recycle/electronics-donation-and-recycling>
- [5] Greenpeace (2020). The E-waste Problem. <https://www.greenpeace.org/india/en/story/10543/why-indias-e-waste-should-worry-us/>
- [6] Forbes (2020). How to Reduce Electronic Waste: 10 Tips Everyone Should Know. <https://www.forbes.com/sites/niallmccarthy/2020/01/20/how-to-reduce-electronic-waste-10-tips-everyone-should-know-infographic/?sh=26e487fc6a7e>

- [7] Murthy, V. and Ramakrishna, S., 2022. A review on global e-waste management: urban mining towards a sustainable future and circular economy. *Sustainability*, 14(2), p.647.
- [8] Vishwakarma, S., Kumar, V., Arya, S., Tembhare, M., Dutta, D. and Kumar, S., 2022. E-waste in Information and Communication Technology Sector: Existing scenario, management schemes and initiatives. *Environmental Technology & Innovation*, 27, p.102797.
- [9] Yusuf, M. (2021). Cellulose-Based Nanomaterials for Water Pollutant Remediation. In: Kharissova O, Martínez L, Kharisov B, *Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications*, Cham; Springer, pp. 213-228. https://doi.org/10.1007/978-3-030-36268-3_17
- [10] Thakur, P. and Kumar, S., 2022. Evaluation of e-waste status, management strategies, and legislations. *International Journal of Environmental Science and Technology*, 19(7), pp.6957-6966.
- [11] Asokan, V.A., Teah, H.Y., Kawazu, E. and Hotta, Y., 2023. Ambitious EV policy expedites the e-waste and socio-environmental impacts in India. *Resources, Conservation and Recycling*, 190, p.106829.
- [12] Maes, T. and Preston-Whyte, F., 2022. E-waste it wisely: Lessons from Africa. *SN Applied Sciences*, 4(3), p.72.
- [13] Almulhim, A.I., 2022. Household's awareness and participation in sustainable electronic waste management practices in Saudi Arabia. *Ain Shams Engineering Journal*, 13(4), p.101729.
- [14] Pandey, P. and Singh, R.K., 2023. E-waste Management Practices in India: Challenges and Approaches. *Microbial Technology for Sustainable E-waste Management*, pp.63-74.
- [15] Raghavendra, T.S., Nagaraja, S.R. and Mohan, K.G., 2023. Convergence of Real-Time Analytical Framework with E-Waste Disposal Using Machine Learning-Centered Hybrid Neural Networks. *Journal of The Institution of Engineers (India): Series C*, pp.1-11.
- [16] Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2021). Global e-waste generation, recycling practices and emerging management challenges. *Journal of Environmental Management*, 280, 111663.
- [17] Singh, R., & Sharma, R. (2021). Electronic waste (E-waste) management: A review. *Journal of Cleaner Production*, 284, 125103.
- [18] Mundada, M.N., Kumar, S. and Shekdar, A.V., 2004. E-waste: a new challenge for waste management in India. *International journal of environmental studies*, 61(3), pp.265-279.
- [19] Shianopkao, S. and Wong, M.H., 2013. Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. *Science of the Total Environment*, 463, pp.1147-1153.
- [20] Baldé, C. P., Wang, F., Kuehr, R., Huisman, J., & Ma, J. (2015). The global e-waste monitor – 2014. United Nations University, IAS – SCYCLE, Bonn, Germany.
- [21] Tsydenova, N., & Bengtsson, M. (2011). Chemical hazards associated with treatment of waste electrical and electronic equipment. *Waste management*, 31(1), 45-58.
- [22] Kang, H.Y. and Schoenung, J.M., 2005. Electronic waste recycling: A review of US infrastructure and technology options. *Resources, Conservation and Recycling*, 45(4), pp.368-400.
- [23] Hsu, E., Barmak, K., West, A.C. and Park, A.H.A., 2019. Advancements in the treatment and processing of electronic waste with sustainability: a review of metal extraction and recovery technologies. *Green Chemistry*, 21(5), pp.919-936.
- [24] Andooz, A., Egbalpour, M., Kowsari, E., Ramakrishna, S. and Cheshmeh, Z.A., 2022. A comprehensive review on pyrolysis of E-waste and its sustainability. *Journal of Cleaner Production*, 333, p.130191.
- [25] Schluep, M., Hagelüken, C., Kuehr, R., & Magalini, F. (2012). Challenges and opportunities in the recovery of gold from electronic waste. *Chemical reviews*, 112(5), 2857-2877.
- [26] Wang, F., Chen, M., & Li, X. (2016). Environmental impact of electronic waste recycling: State of the art and future challenges. *Journal of hazardous materials*, 341, 1-12.
- [27] Puckett, J., Byster, L., Westervelt, S., Gutierrez, R., Davis, S., & Hussain, A. (2002). The Basel Action Network (BAN) study on export of toxic waste from rich to poor countries. *International Journal of Occupational and Environmental Health*, 8(3), 243-252.
- [28] Robinson, B. H. (2009). E-waste: An assessment of global production and environmental impacts. *Science of the Total Environment*, 408(2), 183-191.
- [29] United Nations Environment Programme. (2015). Waste crime - Waste risks: Gaps, challenges and opportunities in the waste sector. Retrieved from https://wedocs.unep.org/bitstream/handle/20.500.11822/9847/WasteCrime_2015.pdf
- [30] Zeng, Y.H., Tang, B., Luo, X.J., Zheng, X.B., Peng, P.A. and Mai, B.X., 2016. Organohalogen pollutants in surface particulates from workshop floors of four major e-waste recycling sites in China and implications for emission lists. *Science of the Total Environment*, 569, pp.982-989.
- [31] Andooz, A., Egbalpour, M., Kowsari, E., Ramakrishna, S. and Cheshmeh, Z.A., 2022. A comprehensive review on pyrolysis of E-waste and its sustainability. *Journal of Cleaner Production*, 333, p.130191.
- [32] Ho, E., Wong, C.P. and King, J.C., 2022. Impact of zinc on DNA integrity and age-related inflammation. *Free Radical Biology and Medicine*, 178, pp.391-397.
- [33] Noel-Brune, M., Goldizen, F.C., Neira, M., van den Berg, M., Lewis, N., King, M., Suk, W.A., Carpenter, D.O., Arnold, R.G. and Sly, P.D., 2013. Health effects of exposure to e-waste. *The Lancet Global Health*, 1(2), p.e70.
- [34] Li, W. and Achal, V., 2020. Environmental and health impacts due to e-waste disposal in China—A review. *Science of the Total Environment*, 737, p.139745.
- [35] Alabi, O.A., Adeoluwa, Y.M., Huo, X., Xu, X. and Bakare, A.A., 2021. Environmental contamination and public health effects of electronic waste: An overview. *Journal of Environmental Health Science and Engineering*, 19, pp.1209-1227.
- [36] Baldé, C. P., Wang, F., Kuehr, R., Huisman, J., & The Global E-waste Statistics Partnership. (2020). The global e-waste monitor 2020: Quantities, flows, and the circular economy potential. United Nations University.
- [37] Kumar, A., & Holuszko, M. E. (2020). Recent trends and future prospects of e-waste management. *Journal of Cleaner Production*, 257, 120479.
- [38] Zhang, K., Song, Q., & Li, J. (2021). E-waste recycling: Challenges and opportunities. *Journal of Hazardous Materials*, 417, 125935.
- [39] He, W., Li, Y., Wang, X., & Liu, X. (2021). E-waste management in China: A review. *Journal of Cleaner Production*, 301, 126832.
- [40] Gao, Y., Zhang, Z., Li, J., Wang, F., & Huang, J. (2020). A review of e-waste recycling policies and their effectiveness in China. *Journal of Cleaner Production*, 263, 121384.
- [41] Ilinkoon, I.M.S.K., Ghorbani, Y., Chong, M.N., Herath, G., Moyo, T. and Petersen, J., 2018. E-waste in the international context—A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. *Waste management*, 82, pp.258-275.
- [42] Wath, S.B., Vaidya, A.N., Dutt, P.S. and Chakrabarti, T., 2010. A roadmap for development of sustainable E-waste management system in India. *Science of the Total Environment*, 409(1), pp.19-32.
- [43] Thakur, P. and Kumar, S., 2022. Evaluation of e-waste status, management strategies, and legislations. *International Journal of Environmental Science and Technology*, 19(7), pp.6957-6966.



Review Article

Foundations, Frameworks, and Evolving Paradigms of Environmental, Social and Governance (ESG)

Anas Jameel^{1*} , Anshal Tiger¹  and Waseem Ahmed² ¹Department of Humanities & Social Sciences, Integral University, Lucknow, India²Glocal Law School, Glocal University, Saharanpur, UP, India

ARTICLE INFO

ABSTRACT

Keywords:

ESG, corporate governance, sustainability reporting, stakeholder theory, socially responsible investment, BRSR, greenwashing, ESG ratings

Article History:

Received: 11-08-2025

Revised: 25-11-2025

Accepted: 20-12-2025

Published: 27-12-2025

Environmental, Social, and Governance (ESG) criteria have emerged over the past two decades as a dominant framework for evaluating corporate sustainability, stakeholder accountability, and long-term value creation. This foundational paper systematically examines the theoretical origins, definitional evolution, and empirical evidence underpinning ESG as a multidimensional governance construct. Drawing on seminal scholarship in corporate social responsibility (CSR), stakeholder theory, agency theory, and institutional economics, the paper traces ESG's conceptual lineage from early socially responsible investment principles through its institutionalization in global reporting standards and regulatory regimes. It critically interrogates the structure of each pillar, Environmental (E), Social (S), and Governance (G), identifying areas of conceptual strength, measurement ambiguity, and normative contestation. The paper further examines ESG's growing integration into capital markets, highlighting evidence on performance linkages, rating divergence, and greenwashing risks. It concludes by identifying key research frontiers, including the reconceptualization of the social pillar, the challenges of ESG in emerging-market contexts, and the tension between disclosure-based compliance and substantive sustainability outcomes. The paper is intended to serve as a conceptual and bibliographic anchor for scholars entering or deepening engagement with the ESG research domain.

1. Introduction

Environmental, Social, and Governance (ESG) criteria represent one of the most consequential conceptual developments in contemporary corporate governance and investment theory. Originating from the early discourse on socially responsible investment (SRI) and the foundational stakeholder turn in management theory, ESG has evolved from a peripheral ethical orientation into a mainstream governance technology employed by investors, regulators, rating agencies, and corporate boards worldwide. The global ESG asset base exceeded USD 35 trillion in 2022 and is projected to surpass USD 50 trillion by 2025, constituting more than a third of total global assets under management (Bloomberg Intelligence, 2021).

Yet ESG remains, in important respects, a contested construct. Despite its rapid institutionalisation, persistent debates surround its definitional boundaries, measurement consistency, normative foundations, and actual effectiveness in producing sustainability outcomes. Scholars have questioned whether ESG constitutes a coherent theoretical framework or a politically convenient aggregation of heterogeneous concerns (Chatterji et al., 2016). Empirical work on the relationship between ESG performance and financial returns produces mixed and context-dependent results (Friede et al., 2015). Meanwhile, the proliferation of ESG rating agencies has produced a paradox of quantification: firms receive divergent scores from different raters on the same underlying data, raising fundamental questions about reliability and construct validity (Berg et al., 2022).

This paper offers a foundational overview of ESG as a scholarly and practical domain. It traces the conceptual origins of

ESG, examines the theoretical architectures that underpin each pillar, surveys the key empirical literature, and identifies emerging debates and research gaps. The paper is structured to serve as a scholarly primer for researchers engaging with ESG, whether approaching it from management, law, finance, accounting, sociology, or public policy perspectives. This paper adopts a narrative and conceptual review approach, synthesising interdisciplinary scholarship across management, finance, law, and public policy. The literature has been selected based on its theoretical influence, empirical relevance, and contribution to key ESG debates, with particular emphasis on studies shaping contemporary academic and regulatory discourse.

2. Conceptual Origins and Theoretical Foundations

This Section situates ESG within its broader intellectual and institutional evolution, tracing how normative debates on corporate responsibility transformed into a globally embedded governance and investment framework.

2.1 From Social Responsibility to ESG

The intellectual lineage of ESG can be traced to mid-twentieth-century debates about the social obligations of corporations. Bowen's (1953) seminal work, *Social Responsibilities of the Businessman*, is widely credited as founding corporate social responsibility (CSR) as an academic field. Bowen argued that businesses, as major centers of decision-making power, bear obligations to society extending beyond profit maximization. This normative claim was radicalized in its opposite direction by Friedman (1970), whose doctrine that the sole social responsibility of business is to increase shareholder

*** Corresponding Author:**✉ anasjameelamu@gmail.com (A. Jameel) <https://doi.org/10.55559/jess.v1i2.637>

© 2024 The Authors. Published by Sprin Publisher, India. This is an open access article published under the CC-BY license

 <https://creativecommons.org/licenses/by/4.0>

profits provided the dominant counter-position. The Friedman-Bowen tension, between shareholder primacy and broader stakeholder accountability, continues to animate contemporary ESG debates.

The theoretical infrastructure of ESG was substantially shaped by Freeman's (1984) stakeholder theory, which reconceived the firm not as an agent of shareholders alone but as a nexus of relationships with a wider set of constituencies, employees, customers, suppliers, communities, and regulators. Stakeholder theory provided ESG with a normative justification: corporate decisions should account for the interests of all parties affected by firm behavior, not merely those who hold equity claims. Building on this, institutional theory (DiMaggio & Powell, 1983) explained how ESG norms spread: firms adopt ESG frameworks not solely because they are intrinsically beneficial, but because conformity with institutional expectations, from investors, regulators, and civil society, confers legitimacy.

2.2 The United Nations Global Compact and Investment Mainstreaming

The contemporary ESG framework gained decisive institutional momentum with the United Nations Global Compact (2000) and the subsequent publication of the Freshfields

Bruckhaus Deringer report (2005), which argued that integrating ESG considerations into investment analysis was permissible, and arguably required, under fiduciary duty. The launch of the UN Principles for Responsible Investment (UNPRI) in 2006, with backing from the UN Secretary-General and major asset managers, marked ESG's formal integration into institutional investment practice (UNPRI, 2006). The term "ESG" itself is widely attributed to the 2004 "Who Cares Wins" report commissioned by the UN Global Compact, which explicitly proposed that embedding ESG criteria in capital market analysis would lead to more sustainable markets and better long-term outcomes for society (UN Global Compact, 2004).

This framing was significant: ESG was not positioned as philanthropy or regulatory compliance, but as a mechanism for aligning long-term financial value with sustainable societal outcomes. The implication, that ESG is both ethically desirable and financially rational, became the dominant paradigm legitimising ESG integration in mainstream asset management.

Having traced the conceptual and institutional evolution of ESG, the following section disaggregates the framework into its three constituent pillars, examining their internal structure, measurement logics, and domain-specific challenges.

3. The Architecture of ESG: Pillar Analysis

Table 1 summarizes the focal domains and representative metrics across the three ESG pillars prior to the detailed analysis in Sections 3.1–3.3.

Table 1. ESG Pillar Architecture: Focal Domains and Representative Metrics

Pillar	Core Focus Areas	Key Metrics
Environmental (E)	Climate change, carbon emissions, water stewardship, biodiversity, circular economy, pollution control	GHG emissions (Scope 1, 2, 3), energy intensity, water withdrawal, waste diversion rate, TCFD disclosures
Social (S)	Labour standards, health & safety, supply chain responsibility, community relations, diversity & inclusion	Lost-time injury rates, living wage compliance, gender pay gap, supplier audit coverage, workforce diversity ratios
Governance (G)	Board composition and independence, executive remuneration, anti-corruption, shareholder rights, transparency	Board independence (%), CEO pay ratio, audit committee quality, whistleblower policy, tax transparency

Note. Adapted from GRI Standards (2021) and SASB Industry Standards (2018).

3.1 The Environmental Pillar

The Environmental pillar addresses how firms interact with natural systems and the ecological consequences of their operations, supply chains, and products. Scholarly and practitioner attention has concentrated heavily on climate-related risk, following the influential Task Force on Climate-related Financial Disclosures (TCFD, 2017) framework, which provided a globally recognized architecture for disclosing climate governance, strategy, risk management, and metrics. Dietz et al. (2016) estimated that climate risks could devalue global financial assets by trillions of dollars under plausible warming scenarios, providing a financial rationale for environmental due diligence that goes beyond ethical imperatives.

Environmental metrics are generally considered the most technically developed of the three pillars, owing to the relative tractability of physical measurement (energy consumption, water

withdrawal, waste generation) and the existence of established international standards such as those of the GHG Protocol and the Global Reporting Initiative (GRI). However, significant challenges remain, including the accounting of Scope 3 (value chain) emissions, the treatment of biodiversity and ecosystem services, and the verification of disclosed data. Concerns about greenwashing, defined as the deliberate or negligent misrepresentation of environmental performance through ESG disclosures, have prompted increasing regulatory scrutiny in jurisdictions including the European Union, the United States, and India (Gillan et al., 2021).

Taken together, the literature suggests that the Environmental pillar is the most operationally mature component of ESG, though its apparent precision masks unresolved issues of boundary definition and verification.

3.2 The Social Pillar

The Social pillar is arguably the most theoretically underspecified of the three, encompassing labor practices, human rights, health and safety, supply chain responsibility, community engagement, and diversity and inclusion. Its definitional breadth creates measurement challenges: unlike greenhouse gas emissions, social constructs such as "inclusion," "dignity," and "fair wages" do not reduce to a single metric and are inherently contested across legal, cultural, and institutional contexts.

Within the Social pillar, gender diversity has received disproportionate academic and regulatory attention, largely because board composition is observable, legally enforceable, and symbolically legible. Meta-analytic evidence suggests a positive but modest and heterogeneous relationship between female board representation and corporate social performance (Byron & Post, 2016; Post & Byron, 2015). However, critical scholars have argued that board-centric indicators conflate elite representation with substantive inclusion, obscuring structural inequalities in remuneration, occupational segregation, and workplace safety that characterize the broader workforce (Kanter, 1977). This limitation becomes particularly acute in emerging economies such as India, where labour informality and gendered occupational segregation render board-level metrics structurally disconnected from the experiences of most women workers.

The review indicates that the social pillar combines high normative ambition with low measurement consensus, resulting in a persistent gap between what is conceptually valued and what is empirically captured.

3.3 The Governance Pillar

Corporate governance, encompassing board independence, executive compensation alignment, anti-corruption practices, and

shareholder rights, has the most extensive academic lineage of the three pillars. Agency theory (Jensen & Meckling, 1976) provides the foundational frame: governance mechanisms exist to align managerial behavior with shareholder interests in contexts of information asymmetry and moral hazard. ESG governance indicators extend this framework to encompass stakeholder-oriented accountability, including transparency in political lobbying, supply chain oversight, and whistleblower protection.

Empirical research has demonstrated that stronger governance is associated with lower cost of capital, lower earnings management, and higher firm valuation (Core et al., 1999). The governance pillar has benefited from more standardized disclosure norms, partly due to the long history of corporate governance codes in major jurisdictions, but important cross-national variation persists, with concentrated ownership structures in many emerging economies complicating the application of governance criteria developed in Anglo-American contexts (La Porta et al., 1998).

Section 3 synthesizes the three pillars of ESG: Environmental, Social, and Governance, by highlighting their distinct conceptual bases, measurement logics, and empirical challenges. As summarized in Table 2, the Environmental pillar benefits from relatively robust standardization and quantifiability, while the social pillar remains conceptually diffuse and methodologically contested. The Governance pillar, in contrast, draws on a well-established theoretical and regulatory lineage but exhibits significant cross-national variation in application. Taken together, the table illustrates that ESG is not a uniform framework, but a composite construct marked by uneven levels of conceptual clarity, data reliability, and institutional maturity across its constituent dimensions.

Table 2: Summary of ESG Pillars

Pillar	Core Focus	Key Frameworks / Theories	Strengths	Key Challenges / Critiques
Environmental	Firm interaction with natural systems; climate risk; resource use; emissions	Task Force on Climate-related Financial Disclosures; Global Reporting Initiative; GHG Protocol	Most technically developed; quantifiable metrics (energy, emissions, water); strong global standards	Scope 3 emissions measurement; biodiversity accounting; data verification; greenwashing concerns
Social	Labour practices; human rights; diversity; inclusion; community impact	Stakeholder Theory; gender diversity literature (Byron & Post)	Expands corporate accountability beyond economics, increasing regulatory focus on diversity	Conceptual ambiguity; difficulty in measurement; over-reliance on board diversity; disconnect from ground realities (especially in emerging economies like India)
Governance	Board structure; executive pay; transparency; shareholder rights; anti-corruption	Agency Theory; corporate governance codes	Strong theoretical foundation; relatively standardized disclosures; clear link to financial performance	Cross-national variation; applicability issues in concentrated ownership systems; limited stakeholder depth in traditional models

Source: Prepare by the Researcher

Unlike the other pillars, governance benefits from a relatively consolidated theoretical and regulatory foundation, though its shareholder-centric origins continue to shape its limitations within ESG

4. ESG Measurement, Ratings, and the Divergence Problem

The quantification of ESG performance is mediated primarily through ESG rating agencies, including MSCI, Sustainalytics, Bloomberg, Refinitiv, and ISS, whose scores are used by investors in portfolio screening, engagement, and stewardship activities. However, a pivotal finding in the empirical literature is that ESG

ratings from different providers exhibit low and sometimes negative correlation with one another, creating what has been termed the "ESG ratings divergence" problem (Berg et al., 2022). In a landmark study, Berg et al. (2022) decomposed ESG rating disagreements into three sources: scope divergence (different agencies measuring different attributes), measurement divergence (different methods for the same attribute), and weight divergence

(different relative importance assigned to categories). Their analysis revealed that measurement divergence was the largest contributor, implicating fundamental differences in how agencies translate observable firm behavior into numeric scores.

This finding has significant implications. If ESG scores measure different things, their use as a basis for capital allocation, regulatory compliance, or academic research produces systematically misleading inferences. Chatterji et al. (2016) demonstrated that even leading social ratings show limited inter-rater agreement and questioned whether aggregated ESG scores can serve as valid indicators of social performance. In response, scholars have advocated for greater transparency in rating methodologies, the separation of ratings by pillar or issue, and the use of raw disclosed data rather than aggregated scores in empirical research.

While measurement challenges complicate the interpretation of ESG scores, a parallel body of literature has sought to evaluate whether these metrics translate into financial performance outcomes.

5. ESG and Financial Performance: Empirical Evidence

A central question in ESG research is whether high-ESG firms systematically outperform their lower-ESG counterparts, whether on a risk-adjusted return basis, cost of capital, or long-run value creation. The largest and most methodologically comprehensive review to date, Friede et al.'s (2015) meta-analysis of approximately 2,200 studies, found that approximately 63% of studies reported a positive relationship between ESG performance and corporate financial performance, approximately 10% found a negative relationship, and the remainder found neutral or mixed results. This aggregate finding has been interpreted as supporting a "business case" for ESG, though the authors cautioned that average effects mask substantial heterogeneity across industries, geographies, measurement approaches, and time horizons.

A nuanced interpretation of the ESG-performance literature emphasizes the importance of distinguishing between voluntary ESG integration and regulatory mandate, between ESG as a risk-management tool and ESG as a strategic differentiator, and between short-term and long-term performance horizons. Khan et al. (2016) provided particularly influential evidence by demonstrating that performance effects are concentrated in ESG issues that are financially material, as defined by the Sustainability Accounting Standards Board (SASB) industry-specific materiality frameworks, suggesting that undifferentiated ESG scores conflate financially relevant sustainability concerns with those that are immaterial to a given firm's value drivers.

In emerging markets, including India, the empirical evidence on ESG-performance linkages is comparatively thinner and more mixed, reflecting data limitations, institutional differences, and the recent vintage of mandatory ESG reporting frameworks. Broader reviews of ESG in emerging markets identify enforcement gaps, state ownership structures, and informal sector linkages as key moderators of ESG's effectiveness (Gillan et al., 2021).

Overall, the literature does not yield a uniform conclusion but instead indicates that ESG-performance relationships are contingent on issue materiality, measurement approach, and institutional context, underscoring the limitations of aggregated ESG indicators.

6. Global Reporting Standards and the Regulatory Landscape

ESG disclosure has been shaped by a proliferating ecosystem of voluntary frameworks and, increasingly, mandatory regulatory requirements. The most prominent voluntary standards include: the Global Reporting Initiative (GRI), which provides universal standards approach for sustainability reporting; the Sustainability Accounting Standards Board (SASB) standards, which take an

industry-specific materiality approach; the International Integrated Reporting Council (IIRC) framework; and the TCFD for climate-specific disclosures. The 2021 formation of the International Sustainability Standards Board (ISSB) under the IFRS Foundation represented a landmark consolidation effort, with the ISSB subsequently issuing IFRS S1 (General Requirements for Sustainability-related Disclosures) and IFRS S2 (Climate-related Disclosures) in 2023 to establish a global baseline for ESG reporting.

On the regulatory side, the European Union's Corporate Sustainability Reporting Directive (CSRD), which came into force in 2023, mandates detailed sustainability disclosures for large companies operating in the EU and represents the most far-reaching mandatory ESG reporting obligation globally (Sharma, 2025). In India, SEBI's BRSR framework, made mandatory for the top 1,000 listed companies by market capitalization from 2022–23, reflects a comparable shift from voluntary to mandatory sustainability reporting within the Indian regulatory architecture. BRSR aligns substantively with international frameworks including the GRI and the National Guidelines on Responsible Business Conduct (NGRBC), while embedding India-specific indicators on workforce composition, community engagement, and product responsibility.

The convergence of reporting frameworks represents a significant institutionalization of ESG, but scholars caution against conflating disclosure with performance. Mandatory reporting can improve information quality and comparability, but it may also generate compliance-oriented reporting behavior that prioritizes indicator optimization over substantive sustainability transformation (Eccles & Serafeim, 2013). This is particularly salient for the social pillar, where disclosure requirements may reward legibility, reporting what is easily quantified, over comprehensiveness.

The convergence of reporting standards reflects institutional consolidation, but the literature cautions that standardisation alone does not resolve underlying issues of comparability, enforcement, and substantive impact.

7. Emerging Debates and Research Frontiers

These debates reflect deeper tensions in ESG's evolution as both a measurement system and a normative framework. The section engages with the most contested and evolving dimensions of ESG, where its rapid institutionalization has generated new tensions around credibility, measurement, and accountability, opening a critical space for empirical scrutiny and theoretical refinement.

7.1 Greenwashing and the Credibility of ESG Claims

Greenwashing, defined broadly as the selective or misleading disclosure of environmental or social performance, constitutes a central integrity challenge for ESG. Empirical work has documented instances of firms achieving high ESG ratings while continuing or expanding environmentally or socially harmful practices, a phenomenon enabled by the flexibility of disclosure norms, the inconsistency of rating methodologies, and the limited third-party verification of reported data (Gillan et al., 2021). Recent regulatory responses, including the European Securities and Markets Authority (ESMA) guidelines on ESG fund naming and the U.S. Securities and Exchange Commission (SEC) climate disclosure rules, reflect a growing institutional recognition that voluntary commitment without enforceable standards is insufficient to prevent reputational exploitation of the ESG label.

7.2 The Social Pillar Reconceptualization

As noted in Section 3.2, the social pillar remains the least theoretically developed component of ESG. A productive research frontier involves reconceptualising inclusion, dignity, and voice

not as attributes of elite governance structures but as organisational capabilities embedded in workforce practices, supply chain standards, and institutional accountability mechanisms. This reconceptualization draws on feminist institutionalist theory (Mackay et al., 2010), Sen's capabilities approach, and substantive equality jurisprudence to argue for a multi-level understanding of social performance that extends beyond the symbolic representational indicators currently dominant in ESG scoring.

7.3 ESG in Emerging Markets

The dominant ESG paradigm has been developed primarily in the context of Anglo-American capital markets, listed corporations, and regulatory environments characterized by relatively strong institutional infrastructure. Its application in emerging markets, including India, China, Brazil, and Sub-Saharan Africa, raises distinctive challenges: high informality in labor markets, concentrated ownership and family firm structures, weaker enforcement of environmental and labor regulations, and limited capacity for third-party ESG verification. Emerging-market scholars have called for context-sensitive adaptations of ESG frameworks that account for these structural differences, rather than wholesale adoption of Western-origin standards whose normative assumptions may be poorly fitted to local conditions (Gillan et al., 2021).

7.4 ESG as Governance Technology versus Ethical Framework

A recurring theoretical debate concerns whether ESG should be understood primarily as a governance technology, a set of disclosure, risk management, and accountability tools designed to enhance long-run firm value, or as an ethical framework oriented toward social and environmental justice outcomes that may be irreducible to financial metrics. This distinction carries significant implications for how ESG is designed, measured, and regulated. Positioning ESG as a governance technology aligns it with shareholder value logic and financial materiality; positioning it as an ethical framework foregrounds obligations to non-investor stakeholders whose claims may not be fully captured in price signals. The resolution of this tension will shape the future trajectory of both ESG scholarship and practice (Eccles & Serafeim, 2013).

8. Conclusion

ESG has become a structuring concept in contemporary corporate governance, investment, and sustainability discourse. This paper has traced its conceptual origins in CSR and stakeholder theory, examined the architecture and measurement challenges of each pillar, reviewed the empirical evidence on ESG and financial performance, and identified key debates shaping the field's development. Several broad conclusions emerge.

First, ESG's theoretical foundations are more pluralistic and contested than its institutionalization as a measurement framework might suggest. The aggregation of environmental, social, and governance concerns into a single score or label entails significant conceptual compression, and much of the empirical inconsistency in the literature reflects this. Disaggregating ESG by pillar, issue, and context produces more tractable and meaningful research questions.

Second, the measurement infrastructure of ESG, while rapidly maturing through the consolidation of reporting standards and the emergence of mandatory disclosure regimes, remains vulnerable to greenwashing, rating divergence, and compliance-oriented behavior. Substantive advances require not merely more disclosure but better-designed disclosure: tied to outcome indicators, subject to independent verification, and calibrated to the material sustainability challenges relevant to specific industries and geographies.

Third, the social pillar represents the most productive frontier for conceptual development. Current frameworks over-rely on legible governance indicators, particularly board representation, at the expense of workforce-level conditions, supply chain accountability, and the structural determinants of substantive inclusion. Theoretically grounded reconceptualization of social performance is both a scholarly priority and a practical necessity for ESG to fulfil its normative promise.

Finally, the globalization of ESG must be accompanied by institutional sensitivity to the contextual conditions that shape sustainability challenges and governance capacities in emerging economies. The uncritical transfer of Anglo-American ESG frameworks risks misspecifying both the problems to be addressed and the metrics best suited to assess progress. A more genuinely global ESG scholarship must engage the institutional, political, and social specifics of diverse regulatory environments.

Viewed collectively, the literature suggests that ESG is best understood not as a unified framework but as an evolving assemblage of partially aligned concepts, metrics, and institutional practices. Its future development will depend on resolving tensions between measurement and meaning, disclosure and impact, and global standardisation and contextual relevance.

References

- Berg, F., Koelbel, J. F., & Rigobon, R. (2022). Aggregate confusion: The divergence of ESG ratings. *Review of Finance*, 26(6), 1315–1344. <https://doi.org/10.1093/rof/rfac033>
- Bloomberg Intelligence. (2021). ESG assets may hit \$53 trillion by 2025, a third of global AUM. Bloomberg Professional Services. <https://www.bloomberg.com/professional/blog/esg-assets-may-hit-53-trillion-by-2025-a-third-of-global-aum/>
- Bowen, H. R. (1953). *Social responsibilities of the businessman*. Harper & Row.
- Byron, K., & Post, C. (2016). Women on boards of directors and corporate social performance: A meta-analysis. *Corporate Governance: An International Review*, 24(4), 428–442. <https://doi.org/10.1111/corg.12165>
- Chatterji, A. K., Durand, R., Levine, D. I., & Touboul, S. (2016). Do ratings of firms converge? Implications for managers, investors, and strategy researchers. *Strategic Management Journal*, 37(8), 1597–1614. <https://doi.org/10.1002/smj.2407>
- Core, J. E., Holthausen, R. W., & Larcker, D. F. (1999). Corporate governance, chief executive officer compensation, and firm performance. *Journal of Financial Economics*, 51(3), 371–406. [https://doi.org/10.1016/S0304-405X\(98\)00058-0](https://doi.org/10.1016/S0304-405X(98)00058-0)
- Dietz, S., Bowen, A., Dixon, C., & Gradwell, P. (2016). 'Climate value at risk' of global financial assets. *Nature Climate Change*, 6(7), 676–679. <https://doi.org/10.1038/nclimate2972>
- DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 48(2), 147–160. <https://doi.org/10.2307/2095101>
- Eccles, R. G., & Serafeim, G. (2013). The performance frontier: Innovating for a sustainable strategy. *Harvard Business Review*, 91(5), 50–60.
- Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.
- Freshfields Bruckhaus Deringer. (2005). A legal framework for the integration of environmental, social and governance issues into institutional investment. UNEP Finance Initiative. <https://www.unepfi.org/wordpress/wp-content/uploads/2022/07/Freshfields-A-legal-framework-for-the-integration-of-ESG-issues-into-institutional-investment.pdf>
- Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000

- empirical studies. *Journal of Sustainable Finance & Investment*, 5(4), 210–233. <https://doi.org/10.1080/20430795.2015.1118917>
- Friedman, M. (1970, September 13). A Friedman doctrine: The social responsibility of business is to increase its profits. *The New York Times Magazine*, 32–33, 122–124.
- Gillan, S. L., Koch, A., & Starks, L. T. (2021). Firms and social responsibility: A review of ESG and CSR research in corporate finance. *Journal of Corporate Finance*, 66, Article 101889. <https://doi.org/10.1016/j.jcorpfin.2021.101889>
- Global Reporting Initiative. (2021). GRI universal standards 2021. GRI. <https://www.globalreporting.org/standards/>
- International Sustainability Standards Board. (2023). IFRS S1 general requirements for sustainability-related financial disclosures and IFRS S2 climate-related disclosures. IFRS Foundation. <https://www.ifrs.org/groups/international-sustainability-standards-board/>
- Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4), 305–360. [https://doi.org/10.1016/0304-405X\(76\)90026-X](https://doi.org/10.1016/0304-405X(76)90026-X)
- Kanter, R. M. (1977). *Men and women of the corporation*. Basic Books.
- Khan, M., Serafeim, G., & Yoon, A. (2016). Corporate sustainability: First evidence on materiality. *The Accounting Review*, 91(6), 1697–1724. <https://doi.org/10.2308/accr-51383>
- La Porta, R., Lopez-de-Silanes, F., Shleifer, A., & Vishny, R. (1998). Law and finance. *Journal of Political Economy*, 106(6), 1113–1155. <https://doi.org/10.1086/250042>
- Mackay, F., Kenny, M., & Chappell, L. (2010). New institutionalism through a gender lens: Towards a feminist institutionalism? *International Political Science Review*, 31(5), 573–588. <https://doi.org/10.1177/0192512110388788>
- Post, C., & Byron, K. (2015). Women on boards and firm financial performance: A meta-analysis. *Academy of Management Journal*, 58(5), 1546–1571. <https://doi.org/10.5465/amj.2013.0319>
- Securities and Exchange Board of India. (2021). Business Responsibility and Sustainability Reporting by listed entities (Circular No. SEBI/HO/CFD/CMD-2/P/CIR/2021/562). SEBI. https://www.sebi.gov.in/legal/circulars/may-2021/business-responsibility-and-sustainability-reporting-by-listed-entities_50096.html
- Sharma, R. (2025). Unveiling the effects of the Corporate Sustainability Reporting Directive (CSRD) on company sustainability reporting practices: a case of German companies. *Sustainability Accounting, Management and Policy Journal*. doi:10.1108/SAMPJ-01-2025-0091
- Sustainability Accounting Standards Board. (2018). SASB standards. SASB. <https://www.sasb.org/standards/>
- Task Force on Climate-related Financial Disclosures. (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. TCFD. <https://www.fsb-tcfd.org/publications/>
- Terjesen, S., Sealy, R., & Singh, V. (2009). Women directors on corporate boards: A review and research agenda. *Corporate Governance: An International Review*, 17(3), 320–337. <https://doi.org/10.1111/j.1467-8683.2009.00742.x>
- UN Global Compact. (2004). Who cares wins: Connecting financial markets to a changing world. United Nations. https://www.unglobalcompact.org/docs/issues_doc/Financial_markets/who_cares_who_wins.pdf
- United Nations Principles for Responsible Investment. (2006). The principles for responsible investment. UNPRI. <https://www.unpri.org/about-us/what-are-the-principles-for-responsible-investment>